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**HANDBOOK OF  
ORE DRESSING**

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**EQUIPMENT AND PRACTICE**



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# HANDBOOK OF ORE DRESSING

EQUIPMENT AND PRACTICE

BY

A. W. ALLEN

METALLURGICAL ENGINEER

AUTHOR OF "MILL AND CYANIDE HANDBOOK"

MEMBER OF THE INSTITUTION OF MINING AND METALLURGY,  
THE MINING AND METALLURGICAL SOCIETY OF AMERICA, AND THE  
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

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## PREFACE

In the following pages an attempt has been made to cover, in condensed form, the various stages in the mechanical handling and preparation of an ore for metallurgical treatment. Amalgamation, concentration, flotation, chemical solution, and smelting—by which either a metal or a mineral is extracted from an ore or concentrate—are considered as essentially metallurgical processes, deserving of specialized treatment, and outside the scope of the book. A line of demarcation between ore dressing and metallurgical extraction and recovery is proposed which, it is hoped, may be found acceptable, as aiding in the more precise interpretation of terms, and the better classification of data.

Information and illustrations have been obtained from a variety of sources, and a bibliography is appended. Appreciative acknowledgment is made to those mentioned, as well as to the publishers, and apologies are tendered to any whose names have been inadvertently omitted.

The aim has been to supply a handy and practical *vade-mecum* for millmen and engineers. The author shares that fallibility which almost invariably characterizes an effort of this kind. He will welcome and appreciate constructive criticism and comment, and the disclosure of any errors that may be noticed.

A. W. A.

NEW YORK,  
Dec. 1919.

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# HANDBOOK OF ORE DRESSING

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## EQUIPMENT AND PRACTICE

### SECTION I

#### INTRODUCTION

The extended ramifications of metallurgical practice and the increasing importance of specialized methods of extraction and recovery of metals and concentrates suggest the necessity for an acceptable definition of the phrase "ore dressing." The fundamental idea underlying the verb "to dress," is "to put in good order" or "to make ready." A second sense, perhaps of wider and older application in metallurgy, is "to cleanse from impurities," and a typical use of the term in this connection is seen in the phrase "the dressing of tin." Tin in this instance refers to the more important tin mineral, cassiterite, known as black tin. The dressing of graphite covers the operations involved in the preparation of the ore and the removal of the valueless material. The graphite is cleansed from associated impurities; hence the phrase, which has a definite meaning. "The dressing of minerals" has been defined<sup>1</sup> as including "all operations that intervene between the extraction of a mineral from its natural deposit and its production in a condition ready for sale or for further use in the arts or manufactures." The treatise in which this definition is found covers crushing and allied operations, as well as concentration. Amalgamation is considered a metallurgical operation, and so outside the scope

of the book. In commenting on this it may be mentioned that various processes have become standard practice since the time when simple concentration of mineral was performed only by gravity methods; so much so that it is difficult to maintain the distinction, or to suggest, for instance, that flotation is less of a metallurgical operation than amalgamation. It will be noted that there is no mention of ore. Without a radical modification in the accepted interpretation of the verb "to dress," the impracticability of a combination of the two words may have been realized. On the other hand, the phrase "ore dressing" was apparently adopted by a number of writers to cover all the different processes involved in the dressing of minerals and metals.

A recognized authority defines<sup>2</sup> "ore dressing" as "the preparation of the ore for the smelter by mechanical means whereby the valuable minerals are concentrated into a smaller bulk and weight by the separation of some of the waste, or whereby two valuable minerals are separated from each other." A detailed criticism of this definition might result in an involved discussion as to acceptable interpretations of "ore" and "waste"; and the first difficulty in dealing with the phrase is encountered. To cleanse a mineral like graphite from impurities means the removal of non-graphitic material; and this is insured by a series of graphite-dressing operations. To cleanse an ore should necessitate nothing more than the removal of waste, as distinct from ore; and this is usually achieved by picking and washing, accompanied sometimes by primary crushing. Hence the need of explaining that, whereas "graphite dressing" means the dressing of graphite, "ore dressing" has been adopted to mean much more than the dressing of ore.

A second definition then followed<sup>3</sup> in which ore dressing was defined as "the process of mechanically separating and saving valuable minerals from the valueless material of an ore whereby its valuable minerals are concentrated into smaller bulk and weight by discarding some of the waste, or the process of mechanically separating two or more minerals, which combined have little value, into two or more products, each of increased value."



The various processes involved in the extraction and recovery of the valuable portions of an ore have specific designations. The problem is to know where to draw the line as to which of them is to be included in ore dressing. The treatises in which these two latter-mentioned definitions are found make especial mention of amalgamation and concentration as phases of ore dressing; but the definition would also include other specialized recovery processes. The same authority defines "coal dressing" as "the removal from coal of the impurities which it always contains." This is a literal adaptation of one of the dictionary definitions of the term. If the interpretation "to cleanse from impurities" is to be taken as definitive of the verb "to dress," then the term "ore dressing" cannot logically be used to represent operations such as graphite dressing, gold dressing or coal dressing.

An alternative definition of ore dressing is inferred where the term is used to refer to "the elimination of the waste portions of metallic ores by mechanical means and without the intervention of the chemical processes of solution, combination or precipitation, or the employment of high temperatures except for roasting or drying."

Sufficient evidence has been brought forward to show that there is a lack of professional agreement as to the meaning of the phrase. This leads to confusion, and prohibits proper classification alike of both ideas and data. The term "ore dressing" has been retained in connection with the reduction and treatment of ores, whereas the processes concerned have undergone extensive modifications and expansions. New methods and inventions have been adopted, more particularly in connection with the extraction and recovery of minerals and metals, for which new and appropriate designatory terms have become necessary. The fact that a number of these processes are still included under the many existing definitions of "ore dressing" is the cause of much confusion; and a reconsideration of the subject is pertinent. One noticeable result of the uncertainty as to the scope of the term is seen in the fact that it is now seldom used by practical

engineers when writing on technical subjects. One of the most important papers, by A. P. Watt, published during 1917 was entitled "Concentration Practice," whereas it referred largely to ore-dressing operations, as distinct from any specialized method of mineral separation or extraction. The result of the uncertainty that exists is that much valuable data are unsuitably indexed and cannot be found when needed. According to the "Engineering Index" authorities (1918), smelting is an ore-dressing operation.

To define the scope of ore dressing logically and authoritatively in harmony with existing definitions is an impossibility. The published interpretations are so varied, and encroach, in many instances, on recovery processes, that a new departure is permissible. A permanent and radical alteration in interpretation is preferable to an attempt to expand periodically the definition, so as to embrace or exclude new treatment processes; and it is suggested that the subject may be considered as "that branch of metallurgy covering the reduction or other mechanical handling of the ore whereby one or more products are obtained in a condition to be treated for the isolation of their valuable contents by amalgamation, concentration, wet-chemical, smelting, or other process of recovery."

To summarize the contentions which have been advanced:

1. There are two interpretations of the verb "to dress," one of which means "to cleanse from impurities." To remove waste from coal is termed "coal dressing;" and to remove gangue from graphite is termed "graphite dressing." The general adoption of the term in this sense would be too cumbersome, as individual designations would be needed in connection with the dressing of each metal or mineral. Interpreted in this way, the use of the word in conjunction with the word "ore," as "ore dressing," has led to confusion and inconsistency.

2. The alternative meaning of the verb "to dress" is "to prepare" or "to arrange." In this sense it is most applicable in the present instance; and, in this treatise, ore dressing is a phrase used only to refer to those preliminary mechanical or semi-mechanical operations that precede or operate concurrently with a specialized method of extraction or recovery.

Overlapping of ore dressing with metallurgical extraction is inevitable, but as a general rule a fairly distinct line of demarcation may be traced. Examples of the simultaneous operation of ore dressing and extraction are seen when an ore is crushed in cyanide solution, or amalgamated in a grinding pan. Roasting occurs as an ore-dressing operation in the preparation of a sulphotelluride ore for cyanide treatment, and as a method of extracting the metal in the volatilization process.

The treatment of the subject of ore dressing may be conveniently considered under the following sub-sections:

- (i) Ore conveyance and storage, elevation, feeding, and sampling.
- (ii) Ore tonnage and moisture estimation.
- (iii) Theory of crushing.
- (iv) Roasting.
- (v) Screening.
- (vi) Coarse or medium crushing in jaw, gyratory, disc or other machines.
- (vii) Stamp milling.
- (viii) Ball milling.
- (ix) Grinding in Chilean, Huntington, and similar types of mills.
- (x) Roll crushing.
- (xi) Regrinding or sliming in pans and tube-mills.
- (xii) Conveyance and elevation of ore pulp.
- (xiii) Classification of ore pulp.
- (xiv) Thickening, settling, and dewatering of ore pulp.

## SECTION II

### ORE CONVEYANCE AND STORAGE, ELEVATION, FEEDING AND SAMPLING

Ore is generally Transported to the Rock Crusher in steel cars of various sizes and shapes, usually mounted on four-wheeled trucks. **Rocker Side-Dump Cars** are largely used for the handling of ore, and may be tipped at either side. Table I gives data with

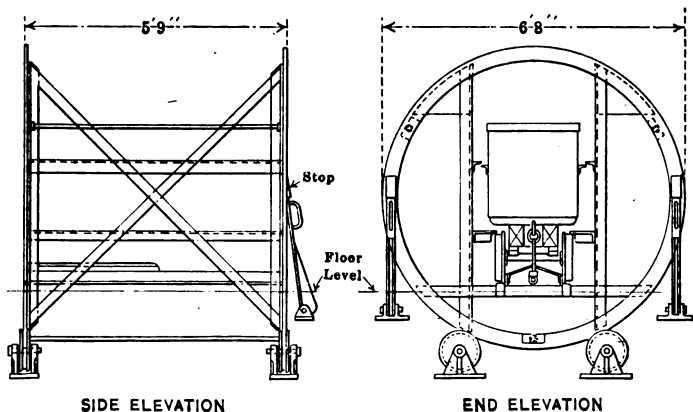


FIG. 1.—Revolving tippler.

reference to **Round-Bottom Rotary Dump Cars**. **Gable Cars** are useful in cases where it is preferable to tip on both sides of the track simultaneously. **Railroad Dump Cars** are usually adopted for ore conveyance to large mills.

A **Revolving Tippler** for ore cars is shown in Fig. 1. The apparatus consists of a framework, carrying rails connecting two points in the track, and mounted by tires and rollers in the manner shown. The empty car is pushed out by the incoming full car, and the framework is balanced to tip automatically, under control of a hand brake.

TABLE I.—ROUND-BOTTOM ROTARY DUMP CARS FOR 18-IN. TRACK<sup>5</sup>

| Capacity,<br>cu. ft. | Wheel         |                 | Wheel<br>base, in. | Dimensions of box |               |               | Thick-<br>ness of<br>steel, in. | Shipping<br>weight,<br>lb. |
|----------------------|---------------|-----------------|--------------------|-------------------|---------------|---------------|---------------------------------|----------------------------|
|                      | Diam.,<br>in. | Tread,<br>in.   |                    | Length,<br>in.    | Width,<br>in. | Depth,<br>in. |                                 |                            |
| 9                    | 10            | 2 $\frac{3}{4}$ | 14                 | 36                | 26            | 18            | $\frac{1}{8}$                   | 650                        |
| 12                   | 10            | 2 $\frac{3}{4}$ | 16                 | 48                | 26            | 18            | $\frac{3}{16}$                  | 725                        |
| 14                   | 10            | 2 $\frac{3}{4}$ | 16                 | 48                | 26            | 21            | $\frac{3}{16}$                  | 750                        |
| 14                   | 12            | 3               | 16                 | 48                | 26            | 21            | $\frac{3}{16}$                  | 875                        |
| 16                   | 10            | 2 $\frac{3}{4}$ | 16                 | 48                | 26            | 24            | $\frac{3}{16}$                  | 770                        |
| 16                   | 12            | 3               | 16                 | 48                | 26            | 24            | $\frac{3}{16}$                  | 900                        |
| 18                   | 10            | 2 $\frac{3}{4}$ | 16                 | 48                | 28            | 24            | $\frac{3}{16}$                  | 790                        |
| 18                   | 12            | 3               | 16                 | 48                | 28            | 24            | $\frac{3}{16}$                  | 920                        |
| 20                   | 12            | 3               | 16                 | 48                | 30            | 24            | $\frac{3}{16}$                  | 930                        |
| 24                   | 12            | 3               | 16                 | 48                | 36            | 24            | $\frac{3}{16}$                  | 970                        |
| 27                   | 12            | 3               | 18                 | 54                | 36            | 24            | $\frac{3}{16}$                  | 1000                       |
| 30                   | 12            | 3               | 18                 | 60                | 36            | 24            | $\frac{3}{16}$                  | 1040                       |
| 32                   | 12            | 3               | 18                 | 60                | 36            | 26            | $\frac{3}{16}$                  | 1075                       |

**Ore Bins** are designed either with flat or sloping bottoms. Flat-bottomed bins are favored by those who maintain that the design allows for an accumulation of "dead" ore for use in the event of an emergency. Sloping-bottomed bins are generally to be preferred and should be designed of a capacity to allow for any reasonable delay due to temporary stoppage of mine operations, the necessity for making rock-breaker repairs, or other emergencies. Large ore bins that will empty without the aid of hand labor are almost invariably a satisfactory investment. The slope of the bin bottom should be about 45 degrees.

**Steel Ore Bins** are generally made in one of two types, viz.: (a) having steel framework supporting comparatively flat sides and bottom plates, and (b) cylindrical bins, which are of simpler and cheaper construction. Height, in the latter type, is out of proportion to capacity, but this objection is counterbalanced by the fact that, if properly designed and stiffened, a series of these cylindrical bins will serve as adequate support for a light railroad.

The **Erection Expense and Cost of Materials** of sloping-bottom ore bins are considerably more than with flat-bottomed bins.

There is also a higher cost due to increased wear and the necessity for the frequent renewal of steel plate or other lining.

The **Approximate Specific Gravities and Weights Per Cubic Foot** of various rocks and other materials handled in ore-dressing operations are given in Table II.

TABLE II.—APPROXIMATE SPECIFIC GRAVITY AND WEIGHT OF VARIOUS SUBSTANCES<sup>6</sup>

|                          | Sp. gr.,<br>av. | Av.<br>wt.<br>per<br>cu. ft. |                              | Sp. gr.,<br>av. | Av.<br>wt.<br>per<br>cu. ft. |
|--------------------------|-----------------|------------------------------|------------------------------|-----------------|------------------------------|
| Earth, etc., excavated   |                 |                              | Minerals                     |                 |                              |
| Clay, dry.....           | 1.0             | 63                           | Asbestos.....                | 2.45            | 153                          |
| Clay, damp, plastic...   | 1.76            | 110                          | Barytes.....                 | 4.5             | 281                          |
| Clay and gravel, dry..   | 1.6             | 100                          | Basalt.....                  | 3.0             | 184                          |
| Earth, dry, loose.....   | 1.2             | 76                           | Bauxite.....                 | 2.55            | 159                          |
| Earth, dry, packed....   | 1.5             | 95                           | Borax.....                   | 1.75            | 109                          |
| Earth, moist, loose...   | 1.3             | 78                           | Chalk.....                   | 2.2             | 137                          |
| Earth, moist, packed..   | 1.6             | 96                           | Clay, marl .....             | 2.2             | 137                          |
| Earth, mud, flowing..    | 1.7             | 108                          | Dolomite.....                | 2.9             | 181                          |
| Earth, mud, packed...    | 1.8             | 115                          | Feldspar, orthoclase .....   | 2.55            | 159                          |
| Riprap, limestone.....   | 1.35            | 82                           | Gneiss, serpentine.....      | 2.55            | 159                          |
| Riprap, sandstone....    | 1.4             | 90                           | Granite, syenite.....        | 2.8             | 175                          |
| Riprap, shale.....       | 1.7             | 105                          | Greenstone, trap.....        | 3.0             | 187                          |
| Sand, gravel, dry, loose | 1.55            | 100                          | Gypsum, alabaster.....       | 2.55            | 159                          |
| Sand, gravel, dry,       |                 |                              | Hornblende.....              | 3.0             | 187                          |
| packed.....              | 1.75            | 110                          | Limestone.....               | 2.66            | 166                          |
| Sand, gravel, wet.....   | 1.9             | 119                          | Marble.....                  | 2.65            | 165                          |
|                          |                 |                              | Magnesite.....               | 3.0             | 187                          |
| Excavations in water     |                 |                              | Phosphate rock, apatite....  | 3.2             | 200                          |
| Sand or gravel.....      | 0.96            | 60                           | Porphyry.....                | 2.75            | 172                          |
| Sand or gravel and clay  | 1.00            | 65                           | Pumice.....                  | 0.62            | 40                           |
| Clay.....                | 1.28            | 80                           | Quartz, flint.....           | 2.65            | 165                          |
| River mud.....           | 1.44            | 90                           | Sandstone, bluestone.....    | 2.35            | 147                          |
| Soil.....                | 1.12            | 70                           | Shale, slate.....            | 2.75            | 172                          |
| Stone riprap .....       | 1.00            | 65                           | Soapstone, talc.....         | 2.7             | 169                          |
| Coal, coke, etc.         |                 |                              | Quarried, piled              |                 |                              |
| Anthracite.....          | 0.84            | 53                           | Basalt, granite, gneiss..... | 1.5             | 96                           |
| Bituminous, lignite...   | 0.75            | 47                           | Limestone, marble, quartz..  | 1.5             | 96                           |
| Peat, turf.....          | 0.37            | 23                           | Sandstone.....               | 1.3             | 82                           |
| Charcoal.....            | 0.20            | 12                           | Shale.....                   | 1.5             | 92                           |
| Coke.....                | 0.44            | 28                           | Greenstone, hornblende....   | 1.7             | 107                          |

**Screw Spiral Conveyors** may be used for the transference of ground ore from one part of the mill to another, or in connection with the feeding of this material to fine-grinding or other machinery. The wear is usually considerable, and the cost of maintenance higher than with other types. It is a suitable system

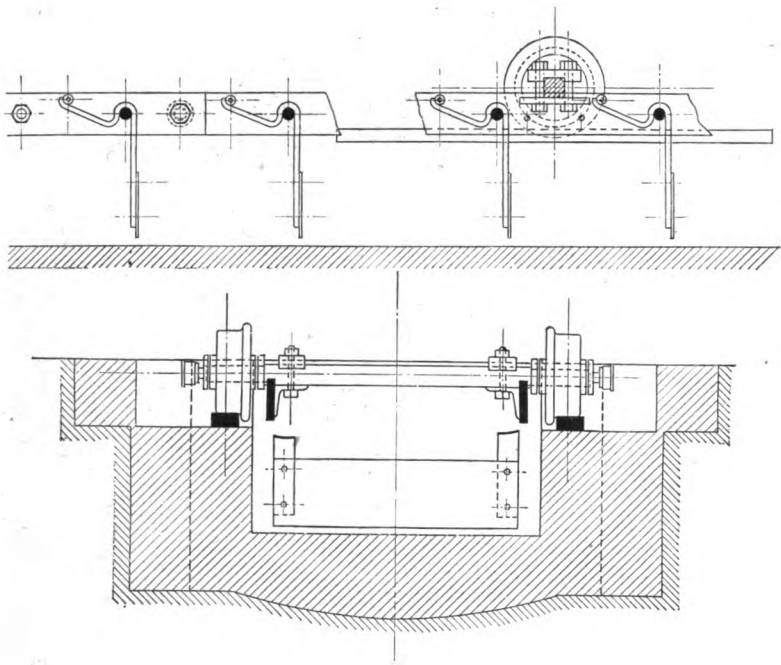


FIG. 2.—Push conveyor for ground ore.<sup>7</sup>

for the conveyance of ore after roasting. A 6-in. diameter spiral at 120 r.p.m. will convey about 120 cu. ft. of material per hour. A 9-in. spiral at 100 r.p.m. will convey about 400 cu. ft. in the same time.

Details of a **Push Conveyor** are given in Fig. 2. The fine ore is fed by this contrivance to a Merton-furnace feed channel. The stroke, effected by means of a crank at the head of the conveyor and operated and controlled by suitable gearing, is 18 in. and

the frequency 20 per minute. The wearing faces consist of 13-gauge renewable steel plate. Several other classes of push conveyors are available, but have no wide application.

**Belt Conveyor Data** will be found in Table III. The same authority (C. Kemble Baldwin) gives the following formulæ

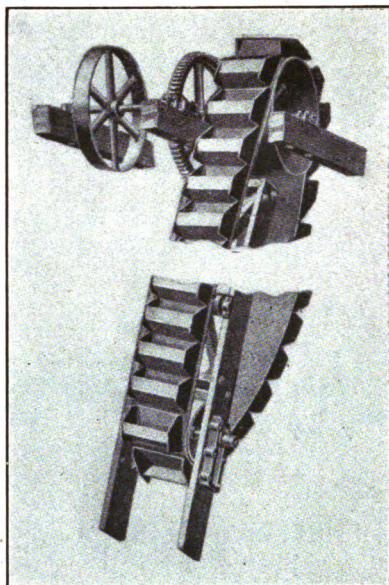


FIG. 3.—Continuous bucket elevator.

for power consumption, where  $C$  equals the power constant;  $T$  the load in tons of 2000 lb. per hour;  $H$  the vertical height the material is lifted in feet, then:

for level conveyors h.p. =  $C T L / 1000$

for inclined conveyors h.p. =  $(C T L / 1000 + (T H / 1000))$

**Conveyor Belt Wear** may be reduced in the case where the material is fairly dry and contains an evenly distributed quantity of fines by placing a small grizzly in the feed chute to form a bed on the belt to receive the coarser portions of the ore.

**A Continuous Bucket Elevator**, suitable for raising broken ore, is shown in Fig. 3. Table IV gives sizes and capacities.



TABLE III.—DATA ON BELT CONVEYORS<sup>6</sup>

| Size                    |                               | Speed | Capacity                                                        |                                                              | Power                                         |                                                  | Belts    |          | Idlers                                                                |                |
|-------------------------|-------------------------------|-------|-----------------------------------------------------------------|--------------------------------------------------------------|-----------------------------------------------|--------------------------------------------------|----------|----------|-----------------------------------------------------------------------|----------------|
| Width of belt in inches | Max. size of pieces in inches |       | Capacity in cu. ft. per hr. at belt speed of 100 ft. per minute | Capacity in tons per hr. at belt speed of 100 ft. per minute | Constant C for material weighing, per cu. ft. | H. p. required for each movable or fixed tripper | Min. ply | Max. ply | Spacing of troughing idlers in ft. for material weighing, per cu. ft. | 50 lb. 100 lb. |
| 12                      | 2                             | 300   | 460                                                             | 23                                                           | 0.177                                         | 0.127                                            | 3        | 4        | 5                                                                     | 4½             |
| 14                      | 2½                            | 300   | 630                                                             | 31                                                           | 0.175                                         | 0.124                                            | 3        | 4        | 5                                                                     | 4½             |
| 16                      | 3                             | 300   | 820                                                             | 41                                                           | 0.172                                         | 0.121                                            | 4        | 5        | 5                                                                     | 4½             |
| 18                      | 4                             | 350   | 1040                                                            | 52                                                           | 0.160                                         | 0.116                                            | 4        | 5        | 4½                                                                    | 4½             |
| 20                      | 5                             | 350   | 1280                                                            | 64                                                           | 0.189                                         | 0.133                                            | 4        | 6        | 4½                                                                    | 4½             |
| 24                      | 8                             | 400   | 1850                                                            | 93                                                           | 0.181                                         | 0.130                                            | 4        | 7        | 4½                                                                    | 4              |
| 30                      | 12                            | 450   | 2900                                                            | 145                                                          | 0.161                                         | 0.119                                            | 5        | 7        | 4½                                                                    | 4              |
| 36                      | 18                            | 500   | 4200                                                            | 210                                                          | 0.150                                         | 0.116                                            | 5        | 8        | 4                                                                     | 3½             |
| 42                      | 20                            | 550   | 5600                                                            | 280                                                          | 0.147                                         | 0.112                                            | 7        | 10       | 4                                                                     | 3              |
| 48                      | 24                            | 600   | 7400                                                            | 370                                                          | 0.138                                         | 0.106                                            | 7        | 11       | 3½                                                                    | 3              |

**Intermittent Bucket** belt-and-bucket elevators are in common use. Table V gives details of their operation, either with broken ore or mill pulp.

TABLE IV.—CONTINUOUS-BUCKET ELEVATOR DATA<sup>s</sup>

| Maximum capacity of elevator in tons per hour | Length between centers of head and foot shaft, ft. | Size and gauge of buckets, in. |        | Width of belt, in. | Total weight, lb. | R.p.m. pinion shaft | R.p.m. head shaft |
|-----------------------------------------------|----------------------------------------------------|--------------------------------|--------|--------------------|-------------------|---------------------|-------------------|
| 30                                            | 30                                                 | 9 × 9                          | No. 16 | 10                 | 3400              | 171                 | 32                |
| 50                                            | 30                                                 | 13 × 10                        | No. 14 | 14                 | 4900              | 197                 | 32                |
| 80                                            | 30                                                 | 15 × 11                        | No. 14 | 16                 | 5900              | 154                 | 27                |
| 120                                           | 30                                                 | 18 × 13                        | No. 12 | 20                 | 6300              | 131                 | 23                |
| 200                                           | 30                                                 | 24 × 14                        | No. 12 | 26                 | 8100              | 135                 | 21                |
| 325                                           | 30                                                 | 30 × 17                        | No. 10 | 32                 | 8500              | 123                 | 19                |
| 450                                           | 30                                                 | 36 × 18½                       | No. 7  | 38                 | 9500              | 109                 | 19                |
| 600                                           | 30                                                 | 42 × 19                        | ¾ in.  | 44                 | 10500             | 112                 | 19                |
| 700                                           | 30                                                 | 48 × 20                        | ¾ in.  | 50                 | 11500             | 112                 | 19                |

TABLE V.—STANDARD VERTICAL MILL ELEVATORS<sup>11</sup>  
Size of Buckets, Bucket Belt, Head, Boot, Driving Pulleys and Speed

| Buckets     |            |            |       | Bucket belt |     | Head pulley |           | Boot pulley |           | T. and L. driving pulleys, and r.p.m. |           |           |             |           |           |                                 |           |           |             |           |           |
|-------------|------------|------------|-------|-------------|-----|-------------|-----------|-------------|-----------|---------------------------------------|-----------|-----------|-------------|-----------|-----------|---------------------------------|-----------|-----------|-------------|-----------|-----------|
|             |            |            |       |             |     |             |           |             |           | Elevators up to 35-ft. centers        |           |           |             |           |           | Elevators 35- to 60-ft. centers |           |           |             |           |           |
|             |            |            |       |             |     |             |           |             |           | Single head                           |           |           | Geared head |           |           | Single head                     |           |           | Geared head |           |           |
| Length, in. | Width, in. | Depth, in. | Style | Width, in.  | Ply | Dia., in.   | Face, in. | Dia., in.   | Face, in. | Dia., in.                             | Face, in. | Ē. c. ft. | Dia., in.   | Face, in. | Ē. c. ft. | Dia., in.                       | Face, in. | Ē. c. ft. | Dia., in.   | Face, in. | Ē. c. ft. |
| 6           | 4          | 4½         | A     | 8           | 5   | 24          | 9         | 20          | 9         | 28                                    | 4½        | 48        | 18          | 4½        | 144       | 18                              | 4½        | 144       | 18          | 4½        | 144       |
| 8           | 5          | 5½         | A     | 10          | 5   | 28          | 11        | 24          | 11        | 32                                    | 4½        | 41        | 22          | 4½        | 123       | 22                              | 4½        | 123       | 22          | 4½        | 123       |
| 10          | 6          | 6½         | A     | 12          | 6   | 32          | 13        | 28          | 13        | 36                                    | 6½        | 36        | 26          | 4½        | 108       | 26                              | 6½        | 96        | 26          | 6½        | 108       |
| 12          | 7          | 7½         | A     | 14          | 6   | 36          | 15        | 32          | 15        | 40                                    | 10½       | 32        | 30          | 4½        | 96        | 30                              | 6½        | 96        | 30          | 6½        | 96        |
| 14          | 7          | 7½         | A     | 16          | 8   | 40          | 17        | 36          | 17        | 44                                    | 12½       | 29        | 30          | 6½        | 116       | 30                              | 8½        | 116       | 30          | 8½        | 116       |
| 16          | 7          | 7½         | A     | 18          | 8   | 44          | 19        | 40          | 19        | 48                                    | 12½       | 26        | 34          | 6½        | 104       | 34                              | 8½        | 104       | 34          | 8½        | 104       |
| 18          | 8          | 7¾         | AA    | 20          | 8   | 48          | 21        | 44          | 21        | 52                                    | 14½       | 24        | 36          | 6½        | 120       | 36                              | 8½        | 120       | 36          | 8½        | 120       |
| 20          | 8          | 7¾         | AA    | 22          | 8   | 52          | 23        | 48          | 23        | 56                                    | 14½       | 22        | 36          | 6½        | 110       | 36                              | 8½        | 110       | 36          | 8½        | 110       |

STANDARD VERTICAL MILL ELEVATORS (*continued*)  
Capacities and Horse Power

| Capacities: 20 cu. ft. of ore = 1 ton |                               |                                             |                     |                                             |                     |                                                            |                       | H.p. required,<br>buckets full |                                |
|---------------------------------------|-------------------------------|---------------------------------------------|---------------------|---------------------------------------------|---------------------|------------------------------------------------------------|-----------------------|--------------------------------|--------------------------------|
| Size of<br>bucket,<br>in.             | Cap. of<br>bucket,<br>cu. in. | Dry material,<br>buckets $\frac{1}{2}$ full |                     | Dry material,<br>buckets $\frac{1}{2}$ full |                     | Tons of mineral<br>per hour, buckets<br>$\frac{1}{2}$ full |                       |                                |                                |
|                                       |                               | Cu. ft.<br>per<br>hour                      | Tons<br>per<br>hour | Cu. ft.<br>per<br>hour                      | Tons<br>per<br>hour | Water 3,<br>mineral 1                                      | Water 5,<br>mineral 1 | Up to<br>35-ft.<br>centers     | 35-ft. to<br>60-ft.<br>centers |
| 6                                     | 55                            | 168                                         | 6.4                 | 192                                         | 9.6                 | 2.4                                                        | 1.6                   | 1.0                            | 2.0                            |
| 8                                     | 115                           | 268                                         | 13.4                | 402                                         | 20.1                | 5.0                                                        | 3.3                   | 2.0                            | 3.5                            |
| 10                                    | 204                           | 474                                         | 23.7                | 711                                         | 35.5                | 8.9                                                        | 5.9                   | 3.5                            | 6.5                            |
| 12                                    | 332                           | 770                                         | 38.5                | 1155                                        | 57.7                | 14.4                                                       | 9.6                   | 6.0                            | 10.0                           |
| 14                                    | 391                           | 906                                         | 45.3                | 1359                                        | 67.9                | 16.9                                                       | 11.3                  | 7.5                            | 12.5                           |
| 16                                    | 467                           | 1082                                        | 54.1                | 1623                                        | 81.1                | 20.2                                                       | 13.5                  | 8.5                            | 15.0                           |
| 18                                    | 500                           | 1158                                        | 57.9                | 1737                                        | 86.8                | 21.7                                                       | 14.4                  | 9.5                            | 16.0                           |
| 20                                    | 560                           | 1292                                        | 64.6                | 1938                                        | 91.9                | 24.3                                                       | 15.3                  | 10.0                           | 17.0                           |

Buckets are spaced 18 in. apart.

Speed of belt 300 ft. per minute.

Horse powers indicated include 5 per cent. for friction.

**Speed, Capacity, and Size of Bucket Elevators**, according to Robins practice, may be found from the bucket-elevator chart given in Fig. 5. To find the h.p. required to operate a vertical-bucket elevator, multiply tons of ore and water per hour by lift in feet and divide by 500. The figure obtained includes an allowance of 100 per cent. of useful work for friction. To find the proper size of a bucket elevator for a given tonnage or volume of material per hour and given weight per cubic foot, commence at left of chart with tons per hour and follow across to diagonal line showing weight per cubic foot, thence down to diagonal line representing the desired speed of elevator, thence across to the right until the diagonal showing the desired spacing of buckets is reached. At the bottom, directly below this intersection, is found the required capacity of bucket in cubic inches. If the hourly capacity is given in cubic feet, commence at the top of the chart and follow down until the desired speed line is found, thence across to spacing as before. The heavy line is an example showing that 65 tons per hour of a material weighing 50 lb. to the cubic foot, with a belt speed of 175 ft. per minute,

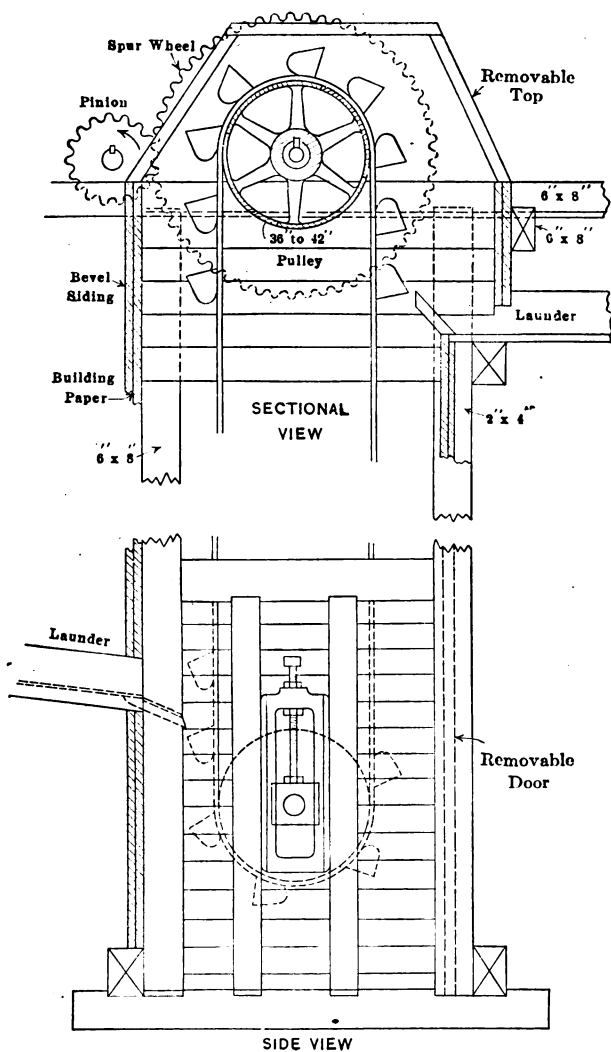


FIG. 4.—Belt-and-bucket elevator.

and 21-in. bucket spacing, will require a working capacity of 740 cubic inches.

**Belt-Elevator Speeds** for pulleys of various diameters may be calculated from the chart given in Fig. 6. **Width and Ply of**

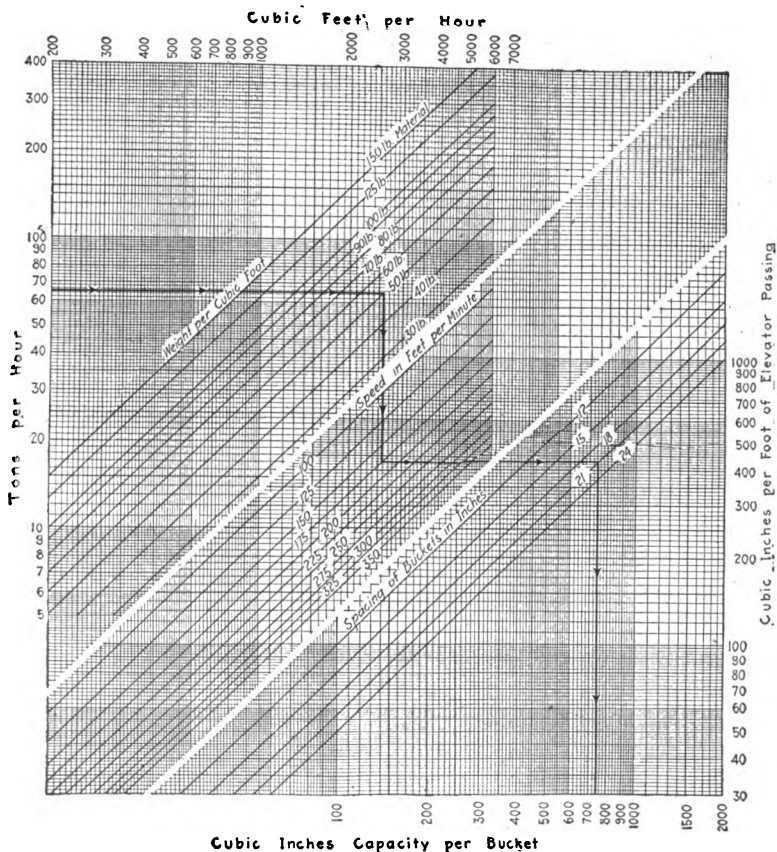
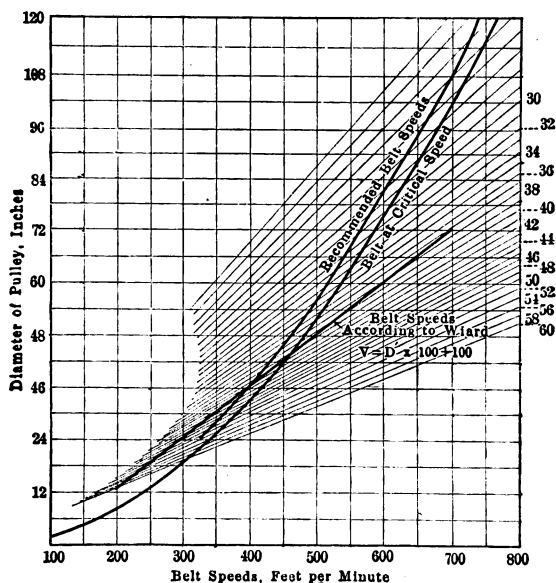


FIG. 5.—Bucket elevator chart.<sup>9</sup>

**Belting** used in connection with belt-and-bucket elevator operation are given in Table VI.

TABLE VI.—WIDTH AND PLY OF BELTING USED IN BELT ELEVATORS <sup>10</sup>

| Height<br>c.-c., ft. | Min.<br>diam.,<br>in. | Recommended<br>diam., in. | Belt,<br>no. plies | Height<br>c.-c.,<br>ft. | Min.<br>diam.,<br>in. | Recommended<br>diam., in. | Belt,<br>no. plies |
|----------------------|-----------------------|---------------------------|--------------------|-------------------------|-----------------------|---------------------------|--------------------|
| 20                   | 24                    | 30                        | 5                  | 80                      | 60                    | 84                        | 12                 |
| 30                   | 30                    | 36                        | 6                  | 90                      | 66                    | 96                        | 12                 |
| 40                   | 36                    | 48                        | 7                  | 100                     | 72                    | 108                       | 14                 |
| 50                   | 42                    | 54                        | 8                  | 120                     | 84                    | 120                       | 16                 |
| 60                   | 48                    | 60                        | 10                 | 140                     | 96                    | 132                       | 18                 |
| 70                   | 54                    | 72                        | 10                 | 160                     | 108                   | 144                       | 20                 |

FIG. 6.—Belt elevator speeds for various pulley diameters. <sup>10</sup>

**Power for Belt-and-Bucket Elevators** is usually applied through gearing, as shown in Fig. 7. **Take-up Boxes** (Fig. 8) are used to allow for the stretching of the belt, and obviate the necessity for frequent shut-downs on this account. The **Feed** should be delivered into the ascending buckets, and not into the

boot of the elevator. **Crowned Pulleys** are to be preferred, and the top (driving) pulley may be lagged with a single layer of belting.

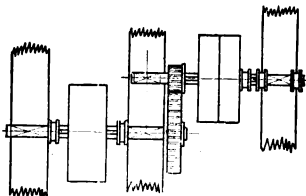


FIG. 7.—Gear drive for elevators.<sup>11</sup>

### FEEDING

**Feed Control of Ore to Chutes** leading to crushing or breaking machinery is regulated by means of gates. Figures 9 and 10 il-

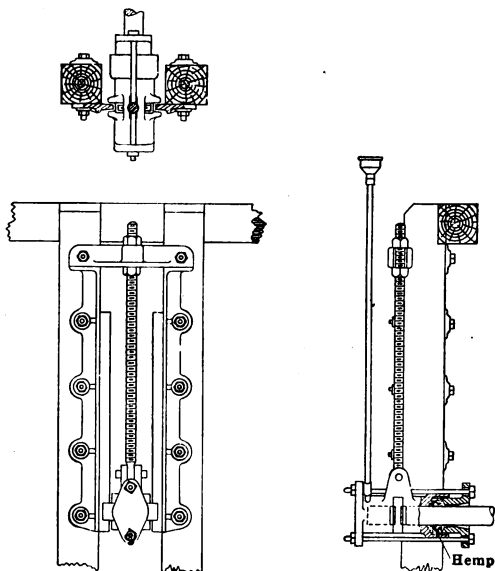
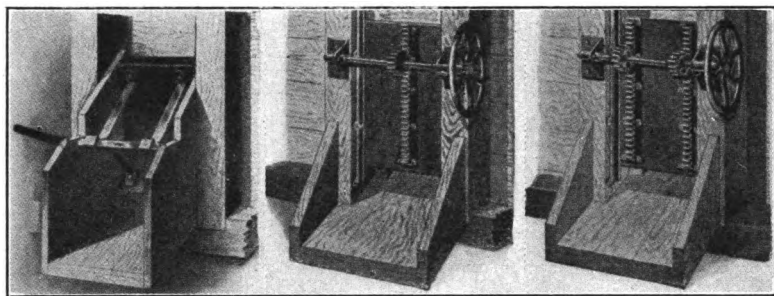


FIG. 8.—Belt-and-bucket elevator take-up boxes.<sup>11</sup>

lustrate the various types in common use. The rack gates are often fitted with counterweights. The sector gate (Fig. 10) is



closed by raising it, by means of a hand lever, through the stream of ore. When full open the back of the gate forms a section of



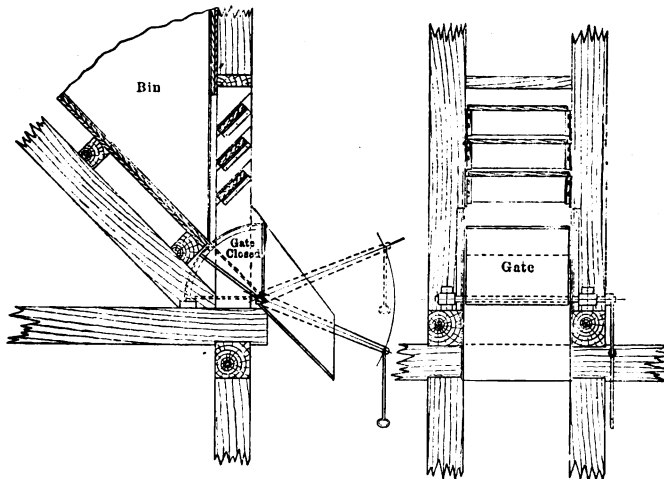
Lever-arc gate

Single-rack gate

Double-rack gate

FIG. 9.—Ore-bin gates.<sup>18</sup>

the chute bottom. Leakage of fines is liable to occur with this type because the joints are in the bottom of the chute.

FIG. 10.—Sector gate.<sup>12</sup>

**Hand Feeding for Primary Crushers** is generally practised in small or medium-sized mills, where it is the usual duty of the

feeder-man to reduce the size of the exceptionally large lumps and also to remove hammer heads, steel, or dynamite which

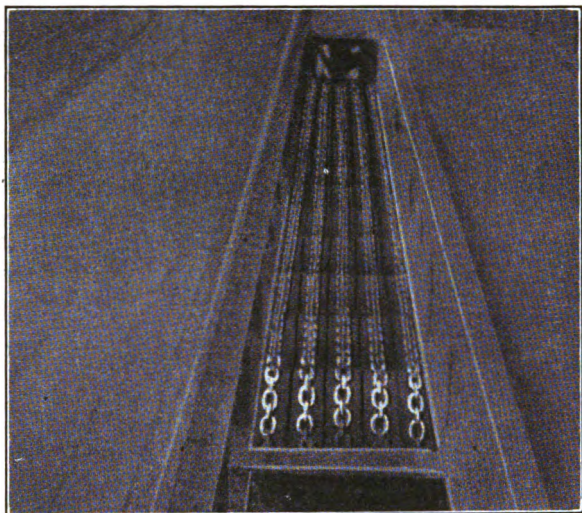


FIG. 11.—Grizzly conveyor.<sup>13</sup>

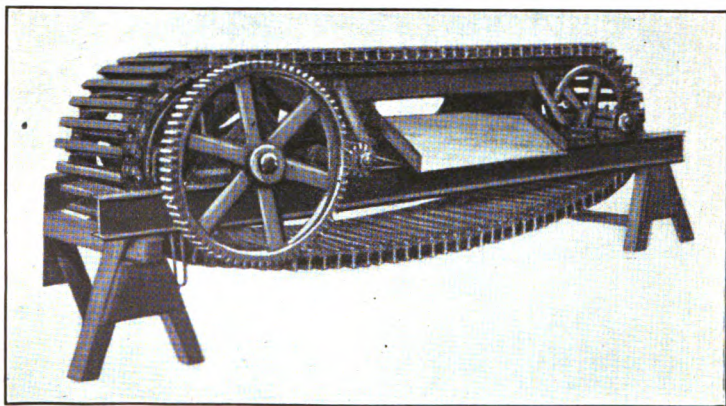


FIG. 12.—Bar-type traveling grizzly.<sup>14</sup>

would cause damage if allowed to remain with the ore. With large mills the problem of primary ore breakage is simplified,

because the capacity of the plant demands the erection of a crusher or crushers of a dimension suitable for the coarsest rock

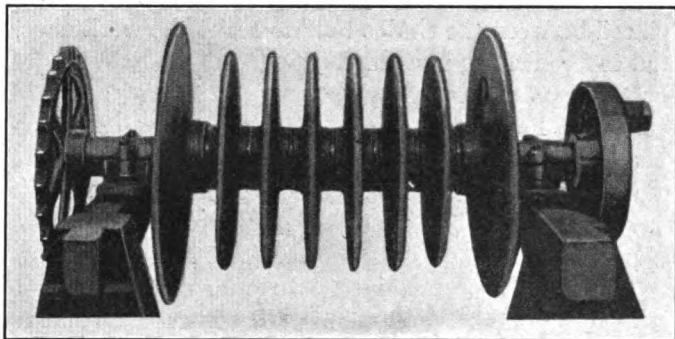


FIG. 13.—Revolving-disc grizzly feeder.<sup>14</sup>

usually received from the mine. Magnets or magnetic pulleys are frequently used to remove steel from crushed ore feed.

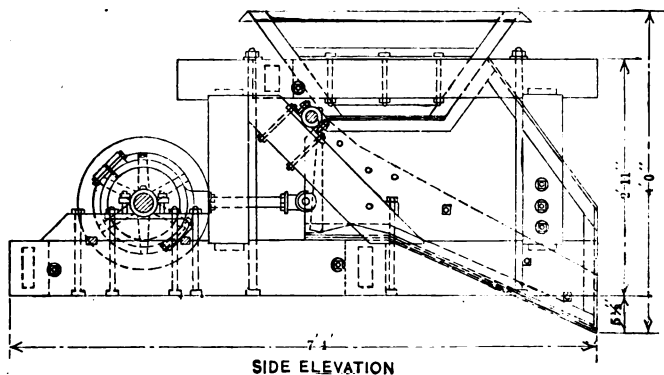


FIG. 14.—Plunger feeder for coarse ore.<sup>15</sup>

The **Chain Grizzly Conveyor** illustrated in Fig. 11 acts as the feeder to a large crusher at the Rowe Mine, Riverton, Minn. The pockets on alternate driving sheaves are arranged so that

adjacent chains travel at different speeds. Masses of agglomerated fine ore are therefore broken up en route to the crusher, the fines falling to the ore bin beneath. Stationary longitudinal bars placed between the chains tend to assist the work of screening, and insure a finer undersize.

The **Bar-Type of Traveling Grizzly** (Fig. 12) is used for feeding crushers. Pieces of ore that become wedged between the bars are automatically released with the oversize, as the bars open up when passing over the sprockets.

The **Revolving-Disc Grizzly Feeder** illustrated in Fig. 13 makes possible the bypassing of fines and the efficient separation of coarse material with a minimum of fall. The feeder illustrated is used in connection with coarse crushers.

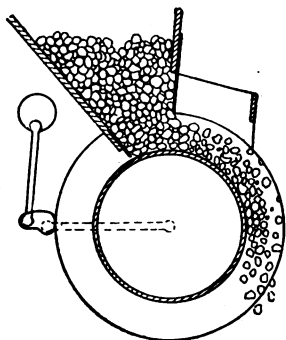


FIG. 15.—Roll feeder.<sup>14</sup>

The **Plunger Feeder for Coarse Ore** (Fig. 14) is suitable for the automatic feeding of mine rock up to 10 in in diameter from chute of storage bin into rock crusher or conveyor. Rate of feed is adjusted by varying the length of the eccentric stroke or by an alteration in the speed.

In **Roll Practice** it is essential that the feed should be evenly distributed over the whole width of the rolls. Short conveyors are sometimes used for this purpose.

**Roll Feeders** (Fig. 15) are chiefly used for a comparatively fine product. They operate on much the same principle as the Challenge feeder and are fitted with a vertical friction disc. Feeders of this type have also been successfully installed for feeding mine rock to large primary crushers.

**Excessive Damage to Belt Conveyors** invariably occurs when no feeder is interposed between breaker or bin, and conveyor. The apron type of feeder suitable for this purpose is shown in

Fig. 16. This feeder may also be used to feed crushers from bins containing mine rock.

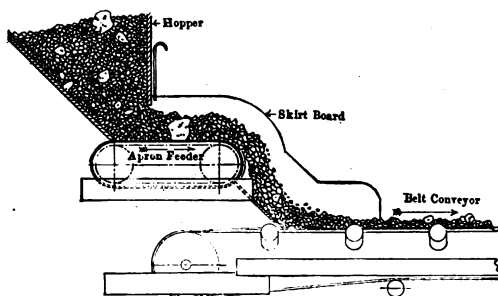


FIG. 16.—Feeder for belt conveyors.<sup>14</sup>

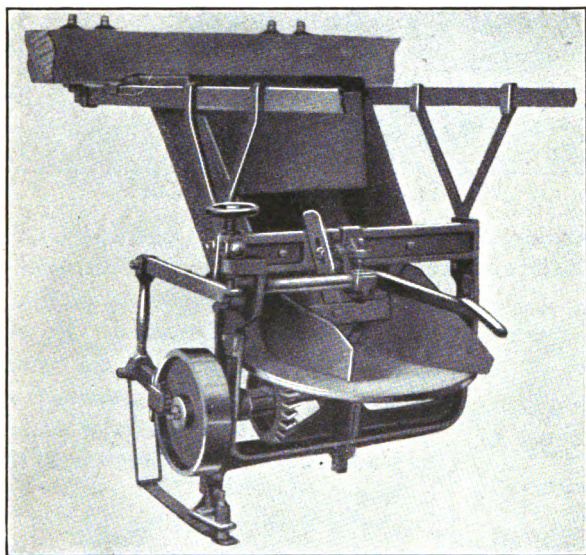


FIG. 17.—Suspended Challenge ore feeder.<sup>11</sup>

**Stamp-Mill Feeders of the Challenge Type** (Figs. 17, 18, and 19) are largely used, in spite of the inherent defects of design

in the older patterns. Extensive repair and renewal work on feeders of this kind is usually unavoidable.

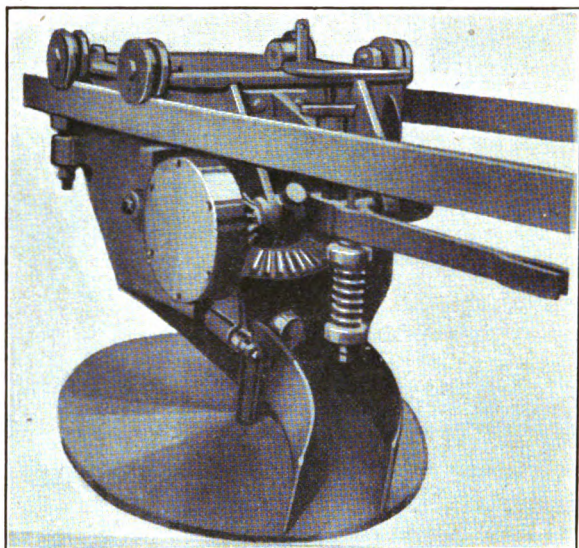


FIG. 18:—Movable Challenge feeder.<sup>16</sup>

The **Monkey-Wrench Feeder** (Fig. 20) operates on the principle of the spanner referred to. The revolving disc and stationary guide, features of the ordinary Challenge type, are retained. No gears are used, and in place of the usual pawl and ratchet a large modified monkey wrench operates on a secondary disc placed below and attached to the main feeder disc.

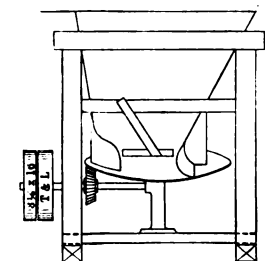


FIG. 19.—Belt-driven Challenge feeder.<sup>17</sup>

The **Plunger Feeder** (Fig. 21) is especially suitable for handling crushed material. It is operated by means of an adjustable eccentric, and can therefore be regulated to suit estimated requirements. This type of feeder is available for any class of crushing or

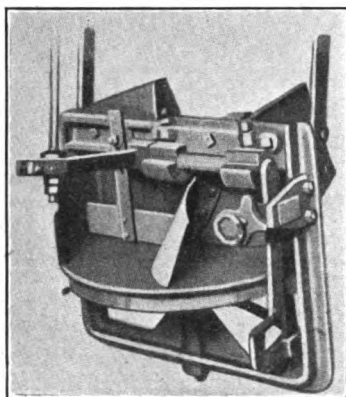


FIG. 20.—Monkey-wrench Challenge feeder.<sup>16</sup>

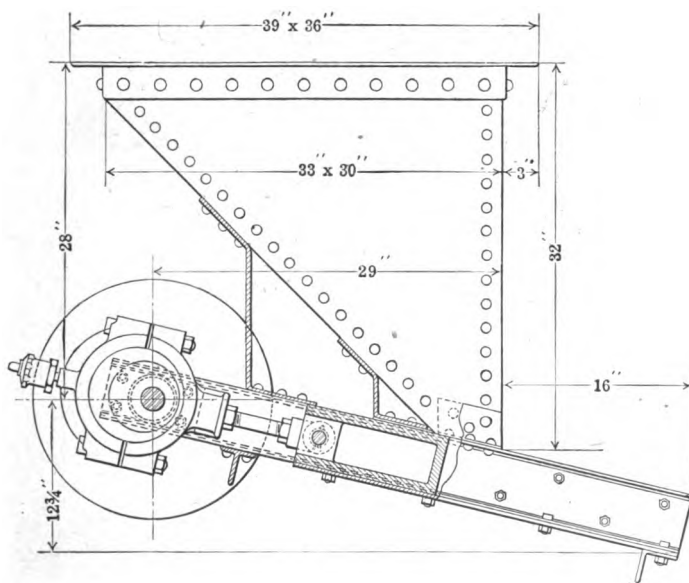


FIG. 21.—Plunger feeder.<sup>18</sup>

milling machine where construction or operation does not permit of automatic adjustment limiting the output from the feeder in accordance with the requirements of the milling machine. A design showing plunger feeder arrangement with direct connection to bin bottom is shown in Fig. 22.

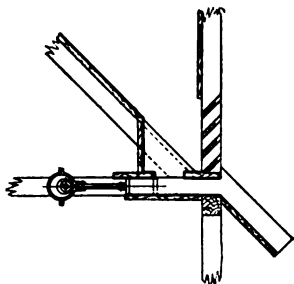


FIG. 22.—Plunger feeder in bin bottom.<sup>10</sup>

An **Automatic Feeder** designed for use with Tremain stamps is shown in Fig. 23. The moving part of the feeder has a surface which sustains but a small part of the weight of ore, the remainder being carried by the hopper. Only a light stroke

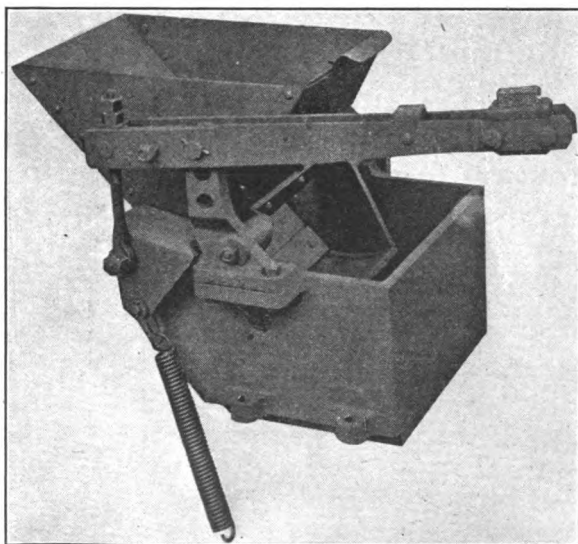


FIG. 23.—Gates automatic feeder.<sup>11</sup>

is necessary, and the feeder is attached directly to the stamp mortar box,



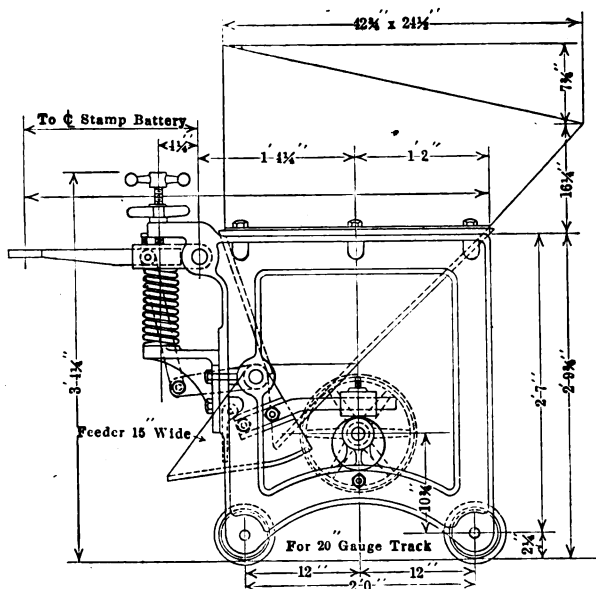


FIG. 24.—Shovel feeder.<sup>19</sup>

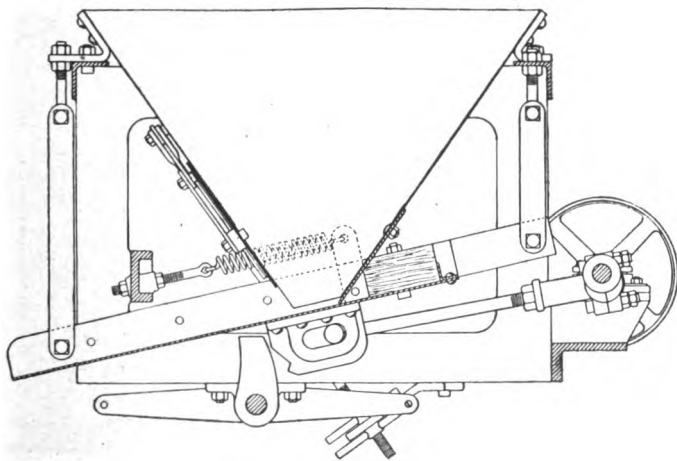


FIG. 25.—Shaking feeder.<sup>12</sup>

In the **Shovel Feeder**, shown in Fig. 24, a projection from the falling stamp throws the boot backward. The counterweight then carries it forward. The combination produces a feeding motion similar to hand shoveling.

The **Shaking Feeder** (Fig. 25) may be adjusted to give an almost continuous flow of crushed ore. This type of feeder is often erected from scrap, and operated by means of a discarded

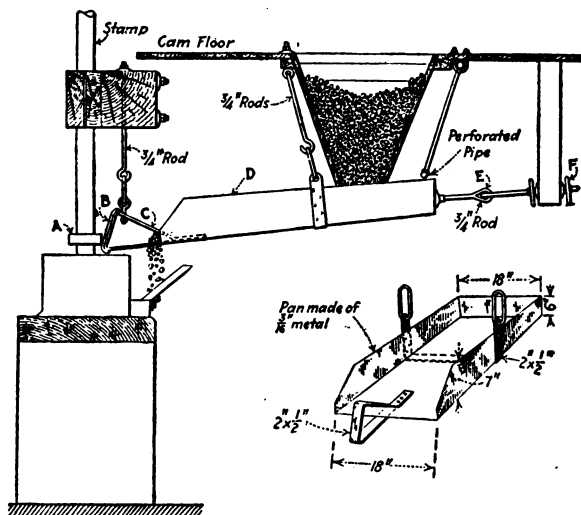


FIG. 26.—Ballow battery feeder.<sup>20</sup>

Wilfley or other concentrator-table head motion. In larger sizes this type has been used as a crusher feeder for coarse ore.

**Bumper-Plate Feeders** are largely used for the mixed feed delivered to ball mills. West Australian practice gives the following data:

|                     |                            |
|---------------------|----------------------------|
| Size of feeder..... | 6 ft. 6 in. long           |
|                     | 2 ft. wide at top          |
|                     | 1 ft. 3 in. wide           |
|                     | at bottom.                 |
| Inclination.....    | 12 deg. to the horizontal. |
| Stroke.....         | 2 in.                      |
| Frequency.....      | 41 per minute.             |

Adjustment of stroke regulates amount of feed.

**Bumper-Plate Feeders** of the Ballow type (Fig. 26) operate by means of a feeder tappet striking a triangular projection

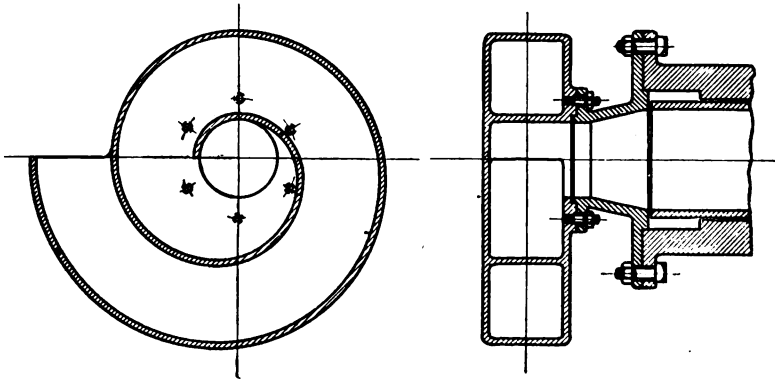


FIG. 27.—Tube-mill feeder.<sup>11</sup>

from a suspended feeder plate. The width of projection engaged by the feeder tappet regulates the jar and, consequently, the feed supply. This type of feeder is especially suitable for

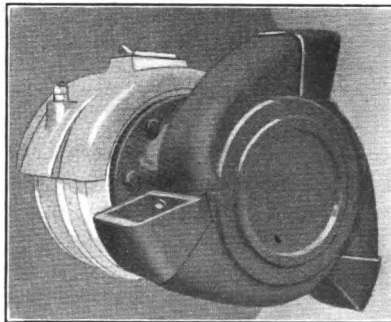


FIG. 28.—Triple spiral feeder.

dry-ore feeding to stamp batteries, is of simple construction, adjustable operation, and requires the minimum of attention and repair.

**Tube-Mill Feeders** are usually of the spiral type (Fig. 27) and are bolted direct to the trunnion. Ample dimension to allow for the passage of large pebbles should be provided, the cutting edge of the spiral should be faced with a renewable steel plate, and the front of the feeder should have a removable disc permitting examination of interior of the mill as well as of the trunnion liners.

**Ball Mills**, other than with peripheral discharge, are usually fitted with spiral feeders of the tube-mill pattern, or the type

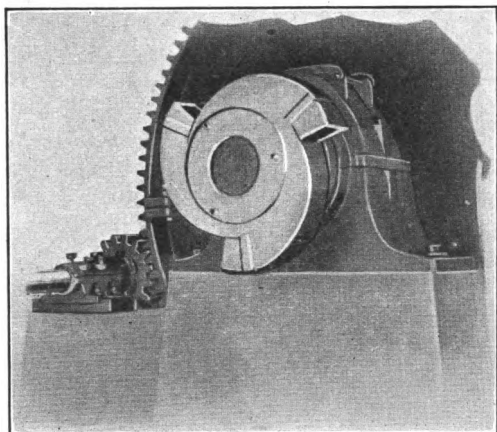


FIG. 29.—Combination triple spiral feeder.

illustrated in Fig. 28. This latter type may also be arranged as a combination feeder in which the pulp may be delivered centrally, and the scoops reserved for feeding the pebbles or balls used as grinding media (Fig. 29). The triple-type spiral feeder is suitable for large-tonnage ball-mill practice.

### ORE SAMPLING

No logical attempt can be made to adhere to theoretical limitations in practical ore-sampling work. When ores are being purchased an agreement between buyer and seller in the matter

of sampling is the primary consideration. In all metallurgical plants efficient sampling is an imperatively necessary phase of operations.

**All Ore-Sampling Methods** must involve bulk reduction by stages. Systematic comminution and thorough mixing are necessary, and both of these steps should preferably be taken before each cutting or splitting operation.

**Suitable Weights to be Taken in Sampling Ore** are indicated in Table VII. These figures are based on the assumption that the weight taken should be proportional to the square of the diameter of the largest particle.

TABLE VII.—WEIGHTS TO BE TAKEN IN SAMPLING ORES<sup>2</sup>

| Weight |        | Diameter of largest particle             |                                |                  |      |                           |                                     |
|--------|--------|------------------------------------------|--------------------------------|------------------|------|---------------------------|-------------------------------------|
| Grams  | Lb.    | Very low-grade or very uniform ores, mm. | Low-grade or uniform ores, mm. | Medium ores, mm. |      | Rich or spotted ores, mm. | Very rich or very spotted ores, mm. |
|        | 20,000 | 207                                      | 114                            | 76.2             | 50.8 | 31.6                      | 5.4                                 |
|        | 10,000 | 147                                      | 80.3                           | 53.9             | 35.9 | 22.4                      | 3.8                                 |
|        | 5,000  | 104                                      | 56.8                           | 38.1             | 25.4 | 15.8                      | 2.7                                 |
|        | 2,000  | 65.6                                     | 35.9                           | 24.1             | 16.1 | 10.0                      | 1.7                                 |
|        | 1,000  | 46.4                                     | 25.4                           | 17.0             | 11.4 | 7.1                       | 1.2                                 |
|        | 500    | 32.8                                     | 18.0                           | 12.0             | 8.0  | 5.0                       | 0.85                                |
|        | 200    | 20.7                                     | 11.4                           | 7.6              | 5.1  | 3.2                       | 0.54                                |
|        | 100    | 14.7                                     | 8.0                            | 5.4              | 3.6  | 2.2                       | 0.38                                |
|        | 50     | 10.4                                     | 5.7                            | 3.8              | 2.5  | 1.6                       | 0.27                                |
|        | 20     | 6.6                                      | 3.6                            | 2.4              | 1.6  | 1.0                       | 0.17                                |
|        | 10     | 4.6                                      | 2.5                            | 1.7              | 1.1  | 0.71                      | 0.12                                |
|        | 5      | 3.3                                      | 1.8                            | 1.2              | 0.8  | 0.5                       |                                     |
|        | 2      | 2.1                                      | 1.1                            | 0.76             | 0.51 | 0.32                      |                                     |
|        | 1      | 1.5                                      | 0.8                            | 0.54             | 0.36 | 0.22                      |                                     |
|        | 0.5    | 1.0                                      | 0.57                           | 0.38             | 0.25 | 0.16                      |                                     |
| 90     | 0.2    | 0.66                                     | 0.36                           | 0.24             | 0.16 | 0.10                      |                                     |
| 45     | 0.1    | 0.46                                     | 0.25                           | 0.17             | 0.11 |                           |                                     |
| 22.5   | 0.05   | 0.33                                     | 0.18                           | 0.12             |      |                           |                                     |
| 9      | 0.02   | 0.21                                     | 0.11                           |                  |      |                           |                                     |
| 4.5    | 0.01   | 0.15                                     |                                |                  |      |                           |                                     |
| 2.25   | 0.005  | 0.10                                     |                                |                  |      |                           |                                     |

**A Sample-Cutting and Reducing Plant** is seldom necessary except where the ore is being purchased on assay content by the milling company, or in the case where subsequent milling operations prohibit the taking of a sample after secondary crushing. In the majority of mills what is generally known as a "battery-feed sample" is taken periodically from the stream of broken ore entering the milling machine. In some cases it has been found possible to hinge a chute, which may be interposed between feeder and mill and across the flow of ore, and so periodically deflect a representative sample for further reduction.

**Sampling Practice in Custom Mills** varies widely, but it is generally considered necessary to reduce the ore to a uniform size of  $2\frac{1}{2}$  in. before any cutting is made. About 20 per cent. is then cut and reduced to  $1\frac{1}{2}$  in. A further 20 per cent. is cut from this and reduced to 1 in. An additional 20 per cent. is then cut and reduced to  $\frac{1}{2}$  in. The final  $\frac{1}{2}$ -in. sample is cut according to its bulk, reground to about  $\frac{1}{8}$  in., again cut, reground to  $\frac{1}{30}$  in., and finally cut to produce about a 3-lb. sample. The latter is split according to requirements, and further reduced with small equipment in the assay office.

**General Mill Sampling** is best effected after secondary crushing. The ore is mixed, the flow is more even, and facilities for sampling are generally better. The value of such sampling is, of course, invalid if the ore is being milled in a solvent of one of the metals for the recovery of which the operations are being conducted. Milling gold or silver ores in cyanide solution, and the inevitable admixture, before secondary crushing, of ore, valuable metal in solution, and an active solvent, precludes the possibility of effective sampling after the ore is wetted.

**Automatic Ore-Pulp Sampling**, as distinct from splitting or dividing, consists of removing a definite proportion of the ore stream either continuously or intermittently, by deflecting the whole stream momentarily, or by passing a cutter across the stream (see Fig. 30).

**Automatic Sample Bulk Reduction** may be accomplished by means of machines known as "splits" or dividers. These

divide the sample into two or more equal and representative portions, of which one or more may be discarded. The same machines may be used to produce duplicate or triplicate samples. The principle of the Jones sample divider will be understood

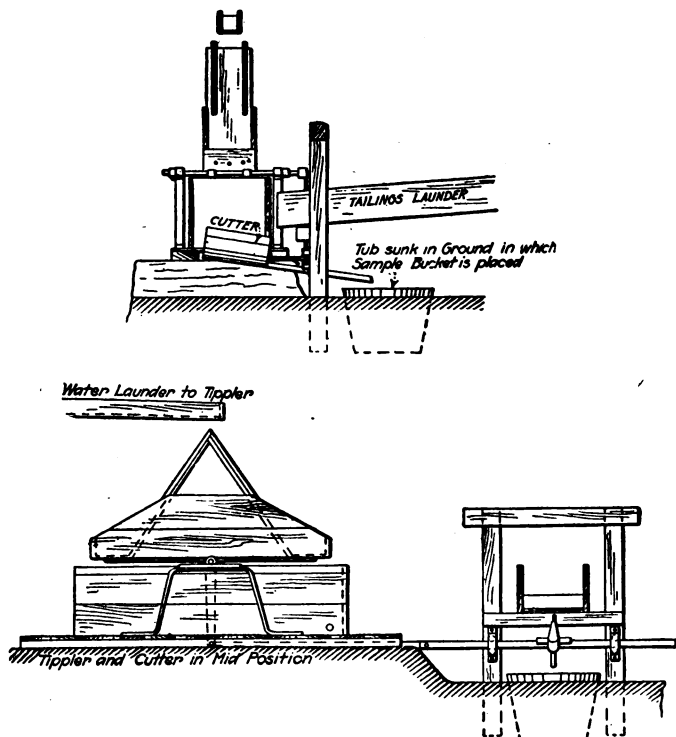


FIG. 30.—Water-actuated pulp sampler.<sup>21</sup>

on reference to Fig. 31. Dimensions are according to size of material and capacity required.

**Mass Reduction in Hand Sampling** by what is known as **Coning and Quartering** is not essential, neither is it so satisfactory as is generally supposed. The labor involved is considerable, and intelligent operation or skilled supervision is necessary.

Best results are obtained by using a large mounted funnel to form the cone, but even then the apex, of soft material, is liable to collapse at intervals and seldom distributes itself evenly. By shoveling from one spot to another and by rejecting alternate shovelfuls the reduction in bulk may be accomplished satisfactorily with minimum labor and in a much shorter time than by coning and quartering.

**Automatic Crushing and Sampling** may be carried out in one machine, such as the Clift. In this apparatus

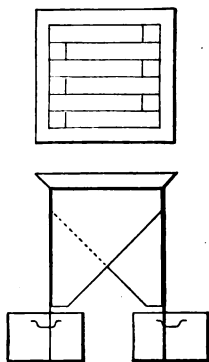


FIG. 31.—Jones split or sample divider.

the stream of ore is divided four times, taking a 20 per cent. cut at each operation, and is crushed three times. The final sample is screened automatically and the oversize is returned for further reduction. A diagram illustrating the operation is shown in Fig. 32. By preceding this apparatus with a large crusher, and by cutting the main stream of ore and sending a proportion to a smaller crusher or rolls, the product from the latter may be sent to the sampling and crushing machine described above.

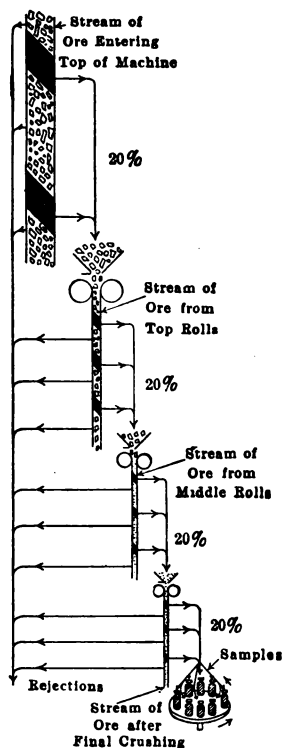
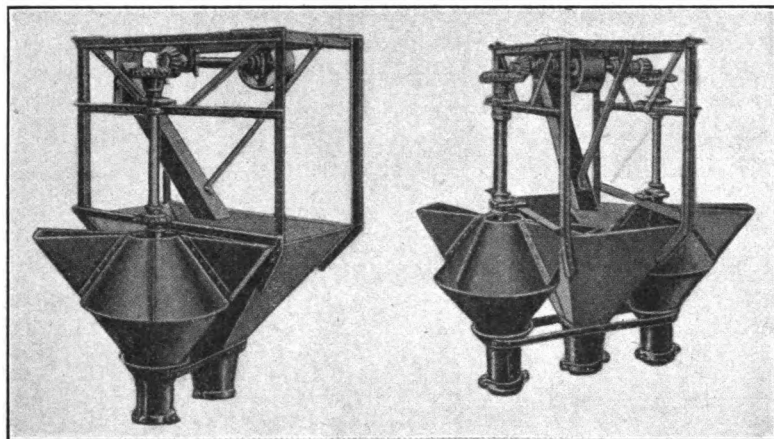


FIG. 32.—Diagram illustrating operation of Clift automatic sampler and crusher.<sup>18</sup>



**Single- and Double-Cut Vezin Samplers** are illustrated in Fig. 33, from which the principle of the apparatus can be easily understood. Width of cutter opening in relation to maximum-sized particle in ore stream should be ample, and speed should be well below the point tending to hold the ore at the periphery of the cutter by centrifugal force.



Single double-cut Vezin sampler

Twin double-cut Vezin sampler

FIG. 33.

**Sampling of Sand** in situ in leaching or collecting vats is usually done with an auger bit. A clean core may be obtained at selected points provided the sand is sufficiently damp to cohere. Sampling of ore in dumps is done by trenching at intervals across the whole width, and sampling the exposed faces at regular distances apart.

## SECTION III

### ORE TONNAGE AND MOISTURE ESTIMATION

**Weighing of Ore** is usually performed in trucks with some type of platform scale. In cases where actual weighing is not practised it is customary to estimate ore weight by calculation of car tally and average. The result is an approximation only. Under- or over-filling of the cars, error in recording numbers, and varia-

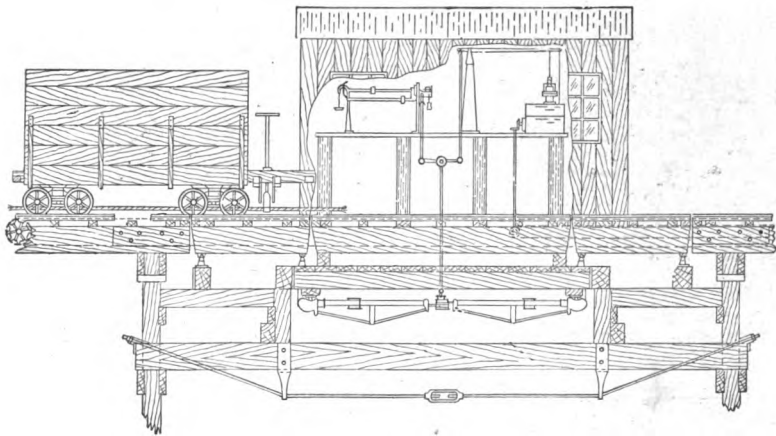


FIG. 34.—Automatic platform weighing scale.<sup>22</sup>

tion in content, resulting in above- or below-normal weights, are among the factors influencing the correctness of result.

The **Automatic Recording of Ore Weight** can be accomplished by means of an apparatus attached to any system of ore conveyance. Figure 34 shows an arrangement automatically to weigh and record weight of ore in cars passing a certain point. Figure 35 gives a sectional view of a machine recording the weight of ore traveling on a belt conveyor. The latter type of apparatus is available for use in connection with bucket, pan, or apron

conveyors, or cable tramways, as well as horizontal or inclined belt conveyors; and an accuracy of 99 per cent. is guaranteed.

The correct **Moisture Percentage** in **Unground Rock** is difficult if not impossible to determine, although commonly attempted. Water occurs in ores as hygroscopic moisture and also as water of crystallization. True ore weight should include the latter but should exclude the former. In estimating moisture it is

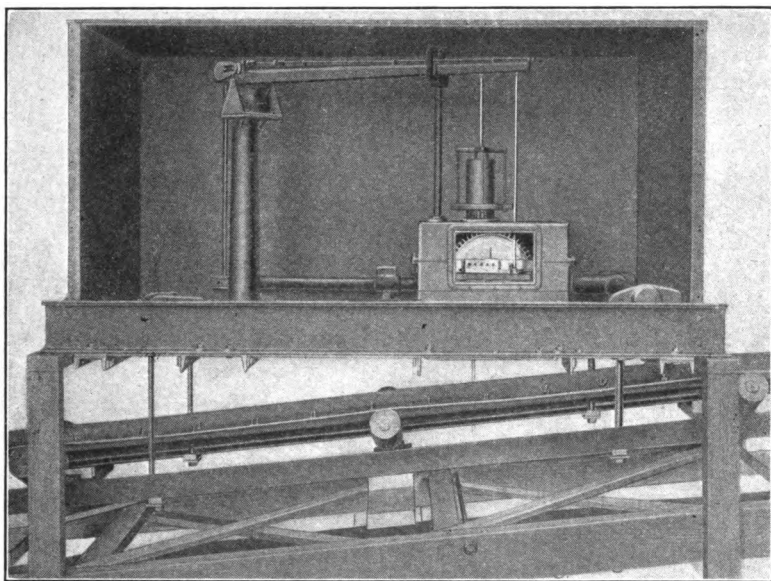


FIG. 35.—Merrick weightometer on belt conveyor. Front sheet of weightometer housing is removed to show interior.<sup>22</sup>

• necessary to follow precise laboratory methods. Over-heating may drive off water of crystallization, and under-heating may result in the retention of hygroscopic moisture, and error in statement. Estimation of moisture percentage by weighing before and after heating to an indefinite temperature for an indefinite time results in an approximation only, and should be considered as such.

**Estimation of Moisture in Ground Ore** is made by selecting a sample without loss of time or undue exposure to the air. An appropriate amount is weighed, and kept at an even temperature of about 110°C. for several hours, and until further heating results in no appreciable reduction in weight. The sample should be cooled in a desiccator before being weighed.

The **Quantity of Material Needed for Moisture Estimation** varies inversely as to the degree of uniformity with which the moisture is distributed. Approximations of moisture content in unground ore are generally made by drying an occasional carload. Moisture content in wet sand or dump tailing is usually calculated from a 100-gm. sample. Pulp samples for tonnage or moisture estimation are generally measured and weighed in a 1000-c.c. flask, and the required figures calculated from tables, without drying the sample.

**Clay and Clayey Ores** may carry a high percentage of hygroscopic moisture without appearing damp to the sense of touch. A considerable amount of hygroscopic moisture may remain after heating to 100° C., whereas water of crystallization may be expelled and the chemical and physical composition of the mineral may be altered by heating above 110° C.

The **Specific Gravity** of an ore is determined by weighing a portion of the dry, ground material and transferring this to a flask of definite cubic content. The flask is then filled with water to the mark and weighed. Then if:

$A$  = weight of dry ore,

$B$  = weight of flask, ore, and water to mark,

$C$  = weight of flask and water to mark,

then:

specific gravity of the ore = weight of ore  $\div$  weight of water it displaces =  $A / [(C + A) - B]$

The **Estimation of Ore-pulp Tonnage** is made, in most instances, by direct weighing and calculation, from a small sample. It is necessary to know the weight of unit volume, or the specific gravity of the pulp, and also the specific gravity of the ore comprising the solid material present. The calculation of dry

tonnage can then be made in several ways by means of the formulæ contained in Table VIII or from the actual equivalents in Table IX.

TABLE VIII.—ORE-PULP TONNAGE FORMULÆ<sup>23</sup>

- $d$  = specific gravity of dry solid (ore, sand, or slime).  
 $p$  = specific gravity of pulp (mixture of water, ore, etc.)  
 $S$  = per cent. by weight of dry solid in pulp.  
     = grams in 100 grams, tons in 100 tons, etc.  
 $R$  = water ratio in pulp.  
     = tons water per ton dry solid.  
     = grams water per gram solid.  
 $V$  = volume per cent. of solid in pulp.  
     = cubic centimeters in 100 c.c.  
     = cubic feet in 100 cu. ft. pulp.  
 $F$  = solid factor.  
     = grams solid in 100 c.c. pulp.  
     = tons solid in 100 fluid tons, or 3200 cu. ft. pulp (approx.)  
     = av. ounces in 0.1 cu. ft. pulp (approx.).  
 $K$  = constant for any particular solid, used to facilitate calculation and depending on the specific gravity of the dry solid.

VALUES OF  $K$  FOR SOLIDS OF KNOWN SPECIFIC GRAVITY

| Specific gravity<br>of dry solid $d$ | Values of<br>$K = \frac{100d}{d-1}$ | Values of<br>27 $K$ | Values of<br>$\frac{100}{K} = \frac{d-1}{d}$ |
|--------------------------------------|-------------------------------------|---------------------|----------------------------------------------|
| 2.2                                  | 183.3                               | 4950                | 0.545                                        |
| 2.3                                  | 176.9                               | 4780                | 0.565                                        |
| 2.4                                  | 171.4                               | 4630                | 0.583                                        |
| 2.5                                  | 166.7                               | 4500                | 0.600                                        |
| 2.6                                  | 162.5                               | 4390                | 0.615                                        |
| 2.7                                  | 158.8                               | 4290                | 0.630                                        |
| 2.8                                  | 155.5                               | 4200                | 0.643                                        |
| 2.9                                  | 152.6                               | 4120                | 0.655                                        |
| 3.0                                  | 150.0                               | 4050                | 0.667                                        |
| 3.1                                  | 147.6                               | 3985                | 0.677                                        |
| 3.2                                  | 145.5                               | 3930                | 0.687                                        |
| 3.3                                  | 143.5                               | 3875                | 0.697                                        |
| 3.5                                  | 140.0                               | 3780                | 0.714                                        |
| 4.0                                  | 133.3                               | 3600                | 0.750                                        |
| 5.0                                  | 125.0                               | 3375                | 0.800                                        |
| 6.0                                  | 120.0                               | 3240                | 0.833                                        |

TABLE IX.—SLIME DENSITY RELATIONS<sup>14</sup>

| Per cent.<br>solids | Ratio of solids<br>to solution | Specific gravity of pulp and volume of one ton in cubic feet, for slimes containing solids of<br>different specific gravities |       |       |       |       |       |       |       |       |       |
|---------------------|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                     |                                | 2.50                                                                                                                          |       | 2.60  |       | 2.70  |       | 2.80  |       | 2.90  |       |
|                     |                                | S. G.                                                                                                                         | Vol.  | S. G. | Vol.  | S. G. | Vol.  | S. G. | Vol.  | S. G. | Vol.  |
| 5                   | 1: 19.000                      | 1031                                                                                                                          | 31.03 | 1032  | 31.01 | 1032  | 30.99 | 1033  | 30.97 | 1034  | 30.95 |
| 6                   | 1: 15.667                      | 1037                                                                                                                          | 30.85 | 1036  | 30.82 | 1039  | 30.79 | 1040  | 30.76 | 1041  | 30.74 |
| 7                   | 1: 13.286                      | 1044                                                                                                                          | 30.66 | 1045  | 30.62 | 1046  | 30.59 | 1047  | 30.56 | 1048  | 30.53 |
| 8                   | 1: 11.500                      | 1050                                                                                                                          | 30.46 | 1052  | 30.43 | 1053  | 30.39 | 1055  | 30.36 | 1055  | 30.32 |
| 9                   | 1: 10.111                      | 1057                                                                                                                          | 30.27 | 1059  | 30.23 | 1060  | 30.19 | 1061  | 30.15 | 1063  | 30.11 |
| 10                  | 1: 9.000                       | 1064                                                                                                                          | 30.08 | 1065  | 30.03 | 1067  | 29.99 | 1068  | 29.95 | 1070  | 29.90 |
| 11                  | 1: 8.091                       | 1071                                                                                                                          | 29.88 | 1073  | 29.83 | 1074  | 29.79 | 1076  | 29.74 | 1078  | 29.69 |
| 12                  | 1: 7.333                       | 1078                                                                                                                          | 29.70 | 1080  | 29.64 | 1082  | 29.59 | 1083  | 29.53 | 1085  | 29.48 |
| 13                  | 1: 6.692                       | 1085                                                                                                                          | 29.50 | 1087  | 29.44 | 1089  | 29.39 | 1091  | 29.33 | 1093  | 29.27 |
| 14                  | 1: 6.144                       | 1092                                                                                                                          | 29.31 | 1094  | 29.24 | 1097  | 29.19 | 1099  | 29.12 | 1101  | 29.06 |
| 15                  | 1: 5.667                       | 1099                                                                                                                          | 29.18 | 1102  | 29.05 | 1104  | 28.99 | 1107  | 28.91 | 1109  | 28.85 |
| 16                  | 1: 5.250                       | 1106                                                                                                                          | 28.93 | 1109  | 28.85 | 1112  | 28.78 | 1115  | 28.71 | 1117  | 28.65 |
| 17                  | 1: 4.882                       | 1114                                                                                                                          | 28.74 | 1117  | 28.65 | 1119  | 28.58 | 1123  | 28.50 | 1125  | 28.44 |
| 18                  | 1: 4.556                       | 1121                                                                                                                          | 28.54 | 1125  | 28.45 | 1128  | 28.38 | 1131  | 28.30 | 1134  | 28.23 |
| 19                  | 1: 4.263                       | 1129                                                                                                                          | 28.35 | 1133  | 28.26 | 1136  | 28.18 | 1139  | 28.09 | 1142  | 28.02 |
| 20                  | 1: 4.000                       | 1136                                                                                                                          | 28.17 | 1140  | 28.06 | 1144  | 27.98 | 1147  | 27.89 | 1151  | 27.81 |
| 21                  | 1: 3.762                       | 1144                                                                                                                          | 27.97 | 1148  | 27.87 | 1152  | 27.77 | 1156  | 27.68 | 1159  | 27.60 |
| 22                  | 1: 3.545                       | 1152                                                                                                                          | 27.78 | 1157  | 27.67 | 1161  | 27.57 | 1165  | 27.47 | 1168  | 27.39 |
| 23                  | 1: 3.348                       | 1160                                                                                                                          | 27.58 | 1165  | 27.47 | 1169  | 27.37 | 1174  | 27.27 | 1177  | 27.18 |
| 24                  | 1: 3.167                       | 1168                                                                                                                          | 27.39 | 1173  | 27.27 | 1178  | 27.17 | 1182  | 27.06 | 1186  | 26.97 |
| 25                  | 1: 3.000                       | 1176                                                                                                                          | 27.21 | 1182  | 27.08 | 1187  | 26.97 | 1191  | 26.85 | 1195  | 26.76 |
| 26                  | 1: 2.846                       | 1185                                                                                                                          | 27.01 | 1190  | 26.88 | 1195  | 26.77 | 1201  | 26.65 | 1205  | 26.55 |
| 27                  | 1: 2.704                       | 1193                                                                                                                          | 26.82 | 1199  | 26.68 | 1205  | 26.56 | 1210  | 26.44 | 1215  | 26.34 |
| 28                  | 1: 2.571                       | 1202                                                                                                                          | 26.62 | 1209  | 26.49 | 1214  | 26.36 | 1220  | 26.24 | 1224  | 26.13 |
| 29                  | 1: 2.448                       | 1211                                                                                                                          | 26.43 | 1217  | 26.29 | 1223  | 26.16 | 1229  | 26.03 | 1234  | 25.92 |
| 30                  | 1: 2.333                       | 1220                                                                                                                          | 26.24 | 1226  | 26.10 | 1233  | 25.95 | 1239  | 25.83 | 1244  | 25.71 |
| 31                  | 1: 2.228                       | 1229                                                                                                                          | 26.05 | 1236  | 25.90 | 1242  | 25.75 | 1249  | 25.63 | 1255  | 25.50 |
| 32                  | 1: 2.125                       | 1238                                                                                                                          | 25.86 | 1245  | 25.70 | 1252  | 25.55 | 1259  | 25.42 | 1265  | 25.29 |
| 33                  | 1: 2.030                       | 1247                                                                                                                          | 25.66 | 1255  | 25.50 | 1262  | 25.35 | 1269  | 25.21 | 1276  | 25.08 |
| 34                  | 1: 1.940                       | 1256                                                                                                                          | 25.47 | 1264  | 25.31 | 1272  | 25.15 | 1279  | 25.01 | 1287  | 24.87 |

|    |          |      |       |      |       |      |       |      |       |      |       |
|----|----------|------|-------|------|-------|------|-------|------|-------|------|-------|
| 35 | 1: 1.857 | 1266 | 25.28 | 1274 | 25.12 | 1283 | 24.95 | 1290 | 24.80 | 1298 | 24.66 |
| 36 | 1: 1.778 | 1276 | 25.09 | 1284 | 24.91 | 1293 | 24.75 | 1301 | 24.60 | 1309 | 24.45 |
| 37 | 1: 1.703 | 1285 | 24.90 | 1295 | 24.71 | 1304 | 24.55 | 1312 | 24.39 | 1320 | 24.24 |
| 38 | 1: 1.632 | 1295 | 24.70 | 1305 | 24.52 | 1314 | 24.35 | 1323 | 24.19 | 1332 | 24.03 |
| 39 | 1: 1.564 | 1305 | 24.51 | 1316 | 24.32 | 1326 | 24.14 | 1335 | 23.98 | 1343 | 23.82 |
| 40 | 1: 1.500 | 1316 | 24.32 | 1326 | 24.13 | 1336 | 23.95 | 1346 | 23.77 | 1355 | 23.61 |
| 41 | 1: 1.439 | 1326 | 24.13 | 1337 | 23.93 | 1348 | 23.74 | 1357 | 23.57 | 1367 | 23.40 |
| 42 | 1: 1.381 | 1337 | 23.94 | 1348 | 23.73 | 1359 | 23.55 | 1370 | 23.36 | 1380 | 23.19 |
| 43 | 1: 1.326 | 1348 | 23.74 | 1359 | 23.53 | 1371 | 23.34 | 1382 | 23.16 | 1392 | 22.99 |
| 44 | 1: 1.273 | 1359 | 23.55 | 1372 | 23.33 | 1383 | 23.15 | 1395 | 22.95 | 1405 | 22.78 |
| 45 | 1: 1.222 | 1370 | 23.36 | 1383 | 23.14 | 1395 | 22.94 | 1407 | 22.74 | 1418 | 22.57 |
| 46 | 1: 1.174 | 1381 | 23.17 | 1395 | 22.94 | 1408 | 22.73 | 1420 | 22.54 | 1432 | 22.36 |
| 47 | 1: 1.128 | 1393 | 22.98 | 1407 | 22.75 | 1420 | 22.54 | 1433 | 22.33 | 1445 | 22.15 |
| 48 | 1: 1.083 | 1404 | 22.78 | 1419 | 22.55 | 1433 | 22.33 | 1446 | 22.12 | 1458 | 21.94 |
| 49 | 1: 1.041 | 1416 | 22.59 | 1431 | 22.35 | 1446 | 22.13 | 1460 | 21.92 | 1473 | 21.73 |
| 50 | 1: 1.000 | 1429 | 22.39 | 1444 | 22.15 | 1460 | 21.92 | 1473 | 21.71 | 1487 | 21.52 |
| 51 | 1: 0.961 | 1441 | 22.21 | 1458 | 21.96 | 1473 | 21.72 | 1488 | 21.51 | 1502 | 21.31 |
| 52 | 1: 0.923 | 1453 | 22.02 | 1471 | 21.76 | 1487 | 21.52 | 1502 | 21.30 | 1517 | 21.10 |
| 53 | 1: 0.887 | 1466 | 21.82 | 1484 | 21.56 | 1501 | 21.32 | 1516 | 21.10 | 1532 | 20.89 |
| 54 | 1: 0.852 | 1479 | 21.63 | 1498 | 21.36 | 1515 | 21.12 | 1532 | 20.89 | 1548 | 20.68 |
| 55 | 1: 0.809 | 1493 | 21.44 | 1512 | 21.17 | 1530 | 20.92 | 1547 | 20.69 | 1564 | 20.47 |
| 56 | 1: 0.786 | 1506 | 21.25 | 1526 | 20.97 | 1545 | 20.72 | 1563 | 20.48 | 1580 | 20.26 |
| 57 | 1: 0.754 | 1520 | 21.06 | 1540 | 20.77 | 1560 | 20.51 | 1579 | 20.27 | 1596 | 20.05 |
| 58 | 1: 0.724 | 1534 | 20.86 | 1555 | 20.58 | 1574 | 20.31 | 1595 | 20.07 | 1613 | 19.84 |
| 59 | 1: 0.695 | 1548 | 20.67 | 1572 | 20.38 | 1591 | 20.11 | 1611 | 19.86 | 1629 | 19.63 |
| 60 | 1: 0.667 | 1563 | 20.48 | 1585 | 20.18 | 1607 | 19.91 | 1628 | 19.66 | 1645 | 19.42 |
| 61 | 1: 0.639 | 1577 | 20.29 | 1601 | 19.98 | 1623 | 19.71 | 1645 | 19.45 | 1664 | 19.21 |
| 62 | 1: 0.613 | 1592 | 20.10 | 1617 | 19.79 | 1641 | 19.51 | 1662 | 19.25 | 1683 | 19.00 |
| 63 | 1: 0.587 | 1608 | 19.90 | 1633 | 19.59 | 1657 | 19.30 | 1681 | 19.04 | 1703 | 18.79 |
| 64 | 1: 0.563 | 1623 | 19.71 | 1650 | 19.40 | 1675 | 19.10 | 1698 | 18.94 | 1723 | 18.58 |
| 65 | 1: 0.538 | 1639 | 19.52 | 1667 | 19.20 | 1692 | 18.90 | 1718 | 18.73 | 1742 | 18.37 |
| 66 | 1: 0.515 | 1656 | 19.32 | 1684 | 19.00 | 1711 | 18.70 | 1738 | 18.53 | 1762 | 18.16 |
| 67 | 1: 0.493 | 1672 | 19.14 | 1701 | 18.80 | 1730 | 18.50 | 1757 | 18.32 | 1783 | 17.95 |
| 68 | 1: 0.471 | 1689 | 18.94 | 1719 | 18.61 | 1749 | 18.30 | 1776 | 18.11 | 1803 | 17.74 |
| 69 | 1: 0.449 | 1706 | 18.75 | 1738 | 18.41 | 1768 | 18.10 | 1797 | 17.81 | 1825 | 17.53 |
| 70 | 1: 0.429 | 1724 | 18.56 | 1757 | 18.21 | 1786 | 17.90 | 1818 | 17.60 | 1847 | 17.32 |

TABLE IX.—SLIME DENSITY RELATIONS (Continued)

| Per cent.<br>solids | Ratio of solids<br>to solution | Specific gravity of pulp and volume of one ton in cubic feet, for slimes containing solids of<br>different specific gravities |       |       |       |       |       |       |       |       |       |
|---------------------|--------------------------------|-------------------------------------------------------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                     |                                | 3.00                                                                                                                          |       | 3.10  |       | 3.20  |       | 3.30  |       | *4.50 |       |
|                     |                                | S. G.                                                                                                                         | Vol.  | S. G. | Vol.  | S. G. | Vol.  | S. G. | Vol.  | S. G. | Vol.  |
| 5                   | 1:19.000                       | 1035                                                                                                                          | 30.93 | 1035  | 30.92 | 1036  | 30.90 | 1036  | 30.89 | 1040  | 30.76 |
| 6                   | 1:15.667                       | 1042                                                                                                                          | 30.72 | 1042  | 30.70 | 1043  | 30.68 | 1043  | 30.66 | 1049  | 30.51 |
| 7                   | 1:13.286                       | 1049                                                                                                                          | 30.51 | 1049  | 30.48 | 1050  | 30.46 | 1051  | 30.43 | 1058  | 30.26 |
| 8                   | 1:11.500                       | 1056                                                                                                                          | 30.30 | 1057  | 30.27 | 1058  | 30.24 | 1059  | 30.21 | 1067  | 30.01 |
| 9                   | 1:10.111                       | 1064                                                                                                                          | 30.09 | 1065  | 30.05 | 1066  | 30.02 | 1067  | 29.99 | 1075  | 29.76 |
| 10                  | 1:9.000                        | 1071                                                                                                                          | 29.87 | 1072  | 29.83 | 1074  | 29.80 | 1075  | 29.77 | 1084  | 29.51 |
| 11                  | 1:8.091                        | 1078                                                                                                                          | 29.65 | 1080  | 29.61 | 1082  | 29.58 | 1083  | 29.54 | 1093  | 29.26 |
| 12                  | 1:7.333                        | 1087                                                                                                                          | 29.44 | 1088  | 29.40 | 1090  | 29.36 | 1091  | 29.32 | 1102  | 29.01 |
| 13                  | 1:6.692                        | 1095                                                                                                                          | 29.23 | 1096  | 29.18 | 1098  | 29.14 | 1099  | 29.10 | 1112  | 28.76 |
| 14                  | 1:6.144                        | 1103                                                                                                                          | 29.01 | 1105  | 28.96 | 1106  | 28.92 | 1108  | 28.88 | 1122  | 28.52 |
| 15                  | 1:5.667                        | 1111                                                                                                                          | 28.80 | 1113  | 28.74 | 1115  | 28.70 | 1117  | 28.66 | 1132  | 28.27 |
| 16                  | 1:5.250                        | 1119                                                                                                                          | 28.59 | 1122  | 28.53 | 1124  | 28.48 | 1125  | 28.43 | 1142  | 28.02 |
| 17                  | 1:4.882                        | 1128                                                                                                                          | 28.37 | 1130  | 28.31 | 1132  | 28.26 | 1134  | 28.21 | 1152  | 27.77 |
| 18                  | 1:4.556                        | 1136                                                                                                                          | 28.16 | 1139  | 28.10 | 1141  | 28.04 | 1143  | 27.99 | 1163  | 27.52 |
| 19                  | 1:4.263                        | 1145                                                                                                                          | 27.95 | 1148  | 27.88 | 1150  | 27.82 | 1153  | 27.76 | 1173  | 27.27 |
| 20                  | 1:4.000                        | 1154                                                                                                                          | 27.73 | 1157  | 27.66 | 1159  | 27.60 | 1162  | 27.54 | 1184  | 27.02 |
| 21                  | 1:3.762                        | 1163                                                                                                                          | 27.52 | 1166  | 27.44 | 1169  | 27.38 | 1171  | 27.32 | 1194  | 26.77 |
| 22                  | 1:3.545                        | 1172                                                                                                                          | 27.31 | 1175  | 27.23 | 1178  | 27.16 | 1181  | 27.09 | 1206  | 26.52 |
| 23                  | 1:3.348                        | 1181                                                                                                                          | 27.09 | 1184  | 27.01 | 1188  | 26.94 | 1191  | 26.87 | 1218  | 26.28 |
| 24                  | 1:3.167                        | 1190                                                                                                                          | 26.88 | 1194  | 26.79 | 1198  | 26.72 | 1201  | 26.65 | 1230  | 26.03 |
| 25                  | 1:3.000                        | 1200                                                                                                                          | 26.67 | 1204  | 26.58 | 1208  | 26.50 | 1211  | 26.42 | 1241  | 25.78 |
| 26                  | 1:2.846                        | 1210                                                                                                                          | 26.45 | 1214  | 26.37 | 1218  | 26.28 | 1222  | 26.20 | 1253  | 25.53 |
| 27                  | 1:2.704                        | 1220                                                                                                                          | 26.24 | 1224  | 26.15 | 1228  | 26.06 | 1232  | 25.98 | 1266  | 25.28 |
| 28                  | 1:2.571                        | 1230                                                                                                                          | 26.03 | 1234  | 25.93 | 1239  | 25.84 | 1243  | 25.75 | 1278  | 25.03 |
| 29                  | 1:2.448                        | 1240                                                                                                                          | 25.81 | 1244  | 25.71 | 1249  | 25.62 | 1253  | 25.53 | 1291  | 24.78 |
| 30                  | 1:2.333                        | 1250                                                                                                                          | 25.60 | 1255  | 25.50 | 1260  | 25.40 | 1264  | 25.31 | 1304  | 24.53 |
| 31                  | 1:2.226                        | 1261                                                                                                                          | 25.39 | 1266  | 25.28 | 1271  | 25.18 | 1275  | 25.08 | 1317  | 24.28 |
| 32                  | 1:2.125                        | 1271                                                                                                                          | 25.17 | 1277  | 25.06 | 1282  | 24.96 | 1287  | 24.86 | 1331  | 24.04 |
| 33                  | 1:2.030                        | 1282                                                                                                                          | 24.96 | 1288  | 24.85 | 1293  | 24.74 | 1299  | 24.64 | 1345  | 23.79 |
| 34                  | 1:1.940                        | 1293                                                                                                                          | 24.75 | 1299  | 24.63 | 1305  | 24.52 | 1311  | 24.41 | 1359  | 23.54 |

\*80 per cent. pyrite and 20 per cent. quartz.



|    |          |      |       |      |       |      |       |      |       |      |       |
|----|----------|------|-------|------|-------|------|-------|------|-------|------|-------|
| 35 | 1: 1.857 | 1304 | 24.53 | 1310 | 24.41 | 1317 | 24.30 | 1323 | 24.19 | 1374 | 23.29 |
| 36 | 1: 1.778 | 1316 | 24.32 | 1322 | 24.19 | 1329 | 24.08 | 1335 | 23.97 | 1389 | 23.04 |
| 37 | 1: 1.703 | 1328 | 24.11 | 1334 | 23.98 | 1341 | 23.86 | 1347 | 23.75 | 1404 | 22.79 |
| 38 | 1: 1.632 | 1340 | 23.89 | 1346 | 23.76 | 1353 | 23.64 | 1360 | 23.52 | 1420 | 22.54 |
| 39 | 1: 1.564 | 1351 | 23.68 | 1358 | 23.55 | 1366 | 23.42 | 1373 | 23.30 | 1435 | 22.29 |
| 40 | 1: 1.500 | 1363 | 23.47 | 1371 | 23.33 | 1379 | 23.20 | 1387 | 23.08 | 1451 | 22.04 |
| 41 | 1: 1.439 | 1376 | 23.26 | 1384 | 23.11 | 1393 | 22.98 | 1400 | 22.85 | 1468 | 21.79 |
| 42 | 1: 1.381 | 1389 | 23.04 | 1397 | 22.89 | 1406 | 22.76 | 1414 | 22.63 | 1485 | 21.55 |
| 43 | 1: 1.326 | 1402 | 22.83 | 1411 | 22.68 | 1419 | 22.54 | 1428 | 22.41 | 1502 | 21.30 |
| 44 | 1: 1.273 | 1415 | 22.61 | 1425 | 22.46 | 1433 | 22.32 | 1442 | 22.18 | 1519 | 21.05 |
| 45 | 1: 1.222 | 1429 | 22.40 | 1438 | 22.24 | 1447 | 22.10 | 1456 | 21.96 | 1538 | 20.80 |
| 46 | 1: 1.174 | 1443 | 22.19 | 1452 | 22.02 | 1462 | 21.88 | 1471 | 21.74 | 1557 | 20.55 |
| 47 | 1: 1.128 | 1457 | 21.97 | 1467 | 21.81 | 1477 | 21.66 | 1487 | 21.51 | 1576 | 20.30 |
| 48 | 1: 1.083 | 1471 | 21.76 | 1483 | 21.60 | 1493 | 21.44 | 1503 | 21.29 | 1495 | 20.05 |
| 49 | 1: 1.041 | 1485 | 21.55 | 1497 | 21.38 | 1508 | 21.22 | 1519 | 21.07 | 1615 | 19.81 |
| 50 | 1: 1.000 | 1500 | 21.33 | 1512 | 21.16 | 1524 | 21.00 | 1535 | 20.85 | 1637 | 19.56 |
| 51 | 1: 0.961 | 1515 | 21.12 | 1528 | 20.94 | 1540 | 20.78 | 1551 | 20.62 | 1658 | 19.31 |
| 52 | 1: 0.923 | 1531 | 20.91 | 1544 | 20.73 | 1556 | 20.56 | 1568 | 20.40 | 1679 | 19.06 |
| 53 | 1: 0.887 | 1547 | 20.69 | 1560 | 20.51 | 1573 | 20.34 | 1585 | 20.18 | 1700 | 18.81 |
| 54 | 1: 0.852 | 1563 | 20.48 | 1577 | 20.29 | 1590 | 20.12 | 1603 | 19.96 | 1724 | 17.56 |
| 55 | 1: 0.809 | 1579 | 20.27 | 1594 | 20.08 | 1608 | 19.90 | 1621 | 19.73 | 1748 | 18.31 |
| 56 | 1: 0.786 | 1596 | 20.05 | 1611 | 19.87 | 1626 | 19.68 | 1640 | 19.51 | 1772 | 18.06 |
| 57 | 1: 0.754 | 1613 | 19.84 | 1628 | 19.65 | 1645 | 19.46 | 1659 | 19.29 | 1796 | 17.81 |
| 58 | 1: 0.724 | 1631 | 19.63 | 1646 | 19.43 | 1663 | 19.24 | 1678 | 19.06 | 1822 | 17.56 |
| 59 | 1: 0.695 | 1649 | 19.41 | 1665 | 19.21 | 1682 | 19.02 | 1697 | 18.84 | 1848 | 17.32 |
| 60 | 1: 0.667 | 1667 | 19.20 | 1684 | 19.00 | 1702 | 18.80 | 1718 | 18.62 | 1875 | 17.07 |
| 61 | 1: 0.639 | 1686 | 18.99 | 1704 | 18.78 | 1722 | 18.58 | 1739 | 18.39 | 1903 | 16.82 |
| 62 | 1: 0.613 | 1705 | 18.77 | 1724 | 18.56 | 1742 | 18.36 | 1761 | 18.17 | 1932 | 16.57 |
| 63 | 1: 0.587 | 1724 | 18.56 | 1745 | 18.34 | 1766 | 18.14 | 1783 | 17.95 | 1961 | 16.32 |
| 64 | 1: 0.563 | 1745 | 18.35 | 1765 | 18.12 | 1786 | 17.92 | 1805 | 17.72 | 1992 | 16.07 |
| 65 | 1: 0.538 | 1765 | 18.13 | 1786 | 17.91 | 1808 | 17.70 | 1828 | 17.50 | 2023 | 15.82 |
| 66 | 1: 0.515 | 1786 | 17.92 | 1808 | 17.69 | 1830 | 17.48 | 1852 | 17.28 | 2054 | 15.57 |
| 67 | 1: 0.493 | 1808 | 17.71 | 1831 | 17.47 | 1853 | 17.26 | 1876 | 17.06 | 2088 | 15.32 |
| 68 | 1: 0.471 | 1830 | 17.49 | 1854 | 17.26 | 1877 | 17.04 | 1901 | 16.83 | 2123 | 15.08 |
| 69 | 1: 0.449 | 1852 | 17.28 | 1878 | 17.04 | 1902 | 16.82 | 1927 | 16.61 | 2159 | 14.83 |
| 70 | 1: 0.429 | 1875 | 17.07 | 1902 | 16.83 | 1926 | 16.60 | 1953 | 16.39 | 2195 | 14.58 |

$$K = \frac{100d}{d-1}.$$

$$d = \frac{p}{1 - R(p-1)} = \frac{Sp}{Sp - 100(p-1)}.$$

$$p = \frac{R+1}{R + \frac{1}{d}} = \frac{100}{100 - \frac{S(d-1)}{d}} = \frac{K}{K-S}.$$

$$S = \frac{100}{R+1} = \frac{100d(p-1)}{p(d-1)} = \frac{K(p-1)}{p}.$$

$$R = \frac{d-p}{d(p-1)} = \frac{1 - \frac{d}{p}}{p-1} = \frac{100-S}{S} = \frac{100}{S} - 1 = \frac{100p}{K(p-1)} - 1.$$

$$F = Sp = \frac{100p}{R+1} = \frac{100d(p-1)}{d-1} = K(p-1).$$

$$V = \frac{F}{d} = \frac{Sp}{d} = \frac{100(p-1)}{d-1} = (K-100)(p-1).$$

$$\begin{aligned} \text{Volume percentage of water in pulp} &= 100 - V = 100 - \frac{F}{d} = \\ p(100 - S) &= \frac{100(d-p)}{d-1}. \end{aligned}$$

$$\begin{aligned} \text{Tons dry solid per 100 tons water} &= \frac{100}{R} = \frac{100S}{100-S} \\ &= \frac{100d(p-1)}{d-p}. \end{aligned}$$

$$\text{Fluid tons to yield 1 ton solid} = \frac{100}{F} = \frac{100}{K(p-1)} = \frac{R+1}{p}.$$

**Sand Tonnage** in situ in a leaching or collecting vat is calculated by allowing a box of 1-cu. ft. capacity to fill with the vat. After drainage of excess moisture, the box and contents are weighed, preferably in the vat by means of a steelyard. A sample of the sand is reserved for immediate moisture determination, a deduction is also made for the weight of the box, and the vat contents are finally calculated from the net weight of the cubic foot of sand and the volume of the vat as filled.

## SECTION IV

### THEORY OF CRUSHING

The **Statement of Crushing Result** in terms of mechanical values must be based on some law defining the ratio between work required or done and reduction in dimension resulting. Much controversy on this point has occurred, and two laws, those of Kick and Rittinger, have been the subject of criticism or support.

**Rittinger's Law** states that the work of crushing is proportional to the reduction in diameter resulting. Richards' interpretation is identical, but may be stated differently, viz.: that the work done is proportional to the surface exposed. By referring to Fig. 36, representing a 1-in. cube, it will be seen that the surface area is  $1[6(1 \times 1)] = 6$  sq. in. If this cube is divided into  $\frac{1}{2}$ -in. cubes by three planes the surface area will be increased to  $8[6(\frac{1}{2} \times \frac{1}{2})] = 12$  sq. in. If reduced to  $\frac{1}{4}$ -in. cubes the surface area will be increased to  $64[6(\frac{1}{4} \times \frac{1}{4})] = 24$  sq. in. The surface areas of the cubes therefore increase in the proportions 6 : 12 : 24 or 1 : 2 : 4, which corresponds to the reciprocals of the lengths of cube sides, or diameters.

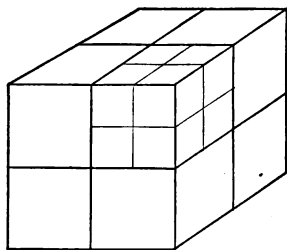


FIG. 36.—Subdivision of cube.

**The Relative Surface Exposed in Each Grade May Be Determined** by dividing the weight of material found in that grade by the average diameter of the particles. This is based on the fact that the total surface area for any definite weight of ore varies inversely as the diameter of the particles composing that weight.

**Average Size of Material** in each grade is determined by finding the arithmetical mean width of the apertures in the screen on which the particles remain and the screen of next larger aperture width. This gives a figure which is as approximately correct as possible where screens with close-order difference in aperture width are used.

**The Reciprocals of the Mean Diameter** of screen aperture width are used by Del Mar in the computation of crushing efficiency comparisons. These reciprocals are multiplied by percentage of material found in the various grades, and the product gives relative surface exposed. By assuming relative surface units and work units as of interchangeable value the comparison may be made in the manner shown in Table X. **Relative Mechanical Efficiencies** may be obtained by multiplying units of work done in each case by duty or output and dividing the result by power consumption.

TABLE X.—COMPARISON OF CRUSHING PERFORMANCE BASED ON  
RITTINGER'S LAW<sup>25</sup>

Reciprocals of Sizes of Screen Apertures

| Mesh | Aperture,<br>in. | Recip-<br>rocals | Mesh | Mean<br>aperture of<br>grade, in. | Recip-<br>rocals | Mean<br>aperture of<br>grade, in. | Recip-<br>rocals |
|------|------------------|------------------|------|-----------------------------------|------------------|-----------------------------------|------------------|
| 20   | 0.0335           | 29.8             | + 20 | 0.0376                            | 26.5             | 0.0376                            | 26.5             |
| 30   | 0.0195           | 51.0             | + 30 | 0.0265                            | 37.7             |                                   |                  |
| 40   | 0.0147           | 68.0             | + 40 | 0.0171                            | 58.4             | 0.0241                            | 41.4             |
| 50   | 0.011            | 91.0             | + 50 | 0.01285                           | 77.7             |                                   |                  |
| 60   | 0.0091           | 110.0            | + 60 | 0.01005                           | 99.5             | 0.0119                            | 83.6             |
| 80   | 0.00675          | 148.0            | + 80 | 0.00792                           | 138.0            | 0.00792                           | 138.0            |
| 100  | 0.0055           | 182.0            | +100 | 0.00612                           | 163.0            | 0.00612                           | 163.0            |
|      |                  |                  | -100 | 0.0049                            | 204.0            | 0.0049                            | 204.0            |
| 120  | 0.0043           | 232.5            | +120 | 0.0049                            | 204.0            | 0.0049                            | 204.0            |
|      |                  |                  | -120 | 0.00395                           | 253.0            | 0.00395                           | 253.0            |
| 150  | 0.0036           | 277.7            | +150 | 0.00395                           | 253.0            | 0.00395                           | 253.0            |
|      |                  |                  | -150 | 0.0033                            | 303.0            | 0.0033                            | 303.0            |
| 200  | 0.003            | 333.3            | +200 | 0.0033                            | 303.0            | 0.0033                            | 303.0            |
|      |                  |                  | -200 | 0.0025                            | 400.0            | 0.0025                            | 400.0            |

TABLE X.—(Continued)  
Screen Analyses of Mill Material

| Mesh             | Mill No. 1              |                         | Mill No. 2              |                         |
|------------------|-------------------------|-------------------------|-------------------------|-------------------------|
|                  | Mill feed,<br>per cent. | Discharge,<br>per cent. | Mill feed,<br>per cent. | Discharge,<br>per cent. |
| On 20.....       | 3.1                     | 0.0                     | 15.1                    | 3.5                     |
| On 40.....       | 15.5                    | 3.2                     | 35.6                    | 21.2                    |
| On 60.....       | 15.6                    | 4.5                     | 10.4                    | 14.1                    |
| On 80.....       | 14.6                    | 10.5                    | 11.1                    | 17.9                    |
| On 100.....      | 9.6                     | 15.8                    | 6.4                     | 11.2                    |
| On 120.....      | 2.4                     | 2.4                     | 0.7                     | 1.6                     |
| Through 120..... | 39.2                    | 63.6                    | 20.7                    | 30.5                    |

Relative Work Done in Mill No. 1

| Mesh                                        | Reciprocal<br>of average<br>size | Feed,<br>per cent. | Relative<br>surface in<br>feed | Discharge,<br>per cent.         | Relative<br>surface in<br>discharge |
|---------------------------------------------|----------------------------------|--------------------|--------------------------------|---------------------------------|-------------------------------------|
| + 20                                        | 26.5                             | 3.1                | 82                             | 0.0                             |                                     |
| + 40                                        | 41.4                             | 15.5               | 641                            | 3.2                             | 132                                 |
| + 60                                        | 83.6                             | 15.6               | 1,304                          | 4.5                             | 376                                 |
| + 80                                        | 138.0                            | 14.6               | 2,015                          | 10.5                            | 1,449                               |
| +100                                        | 163.0                            | 9.6                | 1,564                          | 15.8                            | 2,575                               |
| +120                                        | 204.0                            | 2.4                | 489                            | 2.4                             | 489                                 |
| -120                                        | 253.0                            | 39.2               | 9,917                          | 63.6                            | 16,091                              |
| Units of work in feed.....                  |                                  |                    | 16,012                         | Units of work<br>in discharge.. |                                     |
| Units of work in feed.....                  |                                  |                    |                                | 21,112<br>16,012                |                                     |
| Difference, units of work done per ton..... |                                  |                    |                                |                                 | 5,100                               |

TABLE X.—(Continued)

## Relative Work Done in Mill No. 2

| Mesh                                        | Reciprocal<br>of average<br>size | Feed,<br>per cent. | Relative<br>surface in<br>feed | Discharge,<br>per cent.         | Relative<br>surface in<br>discharge |
|---------------------------------------------|----------------------------------|--------------------|--------------------------------|---------------------------------|-------------------------------------|
| + 20                                        | 26.5                             | 15.1               | 400                            | 3.5                             | 92                                  |
| + 40                                        | 41.4                             | 35.6               | 1,473                          | 21.2                            | 877                                 |
| + 60                                        | 83.6                             | 10.4               | 919                            | 14.1                            | 1,178                               |
| + 80                                        | 138.0                            | 11.1               | 1,532                          | 17.9                            | 2,470                               |
| +100                                        | 163.0                            | 6.4                | 1,043                          | 11.2                            | 1,825                               |
| +120                                        | 204.0                            | 0.7                | 143                            | 1.6                             | 326                                 |
| -120                                        | 253.0                            | 20.7               | 5,237                          | 30.5                            | 7,716                               |
| Units of work in feed.....                  |                                  |                    | 10,747                         | Units of work<br>in discharge.. |                                     |
| Units of work in feed.....                  |                                  |                    |                                |                                 | 14,484                              |
| Difference, units of work done per ton..... |                                  |                    |                                |                                 | 3,737                               |

The **Crushing Efficiencies of Various Milling Machines**, calculated on the basis of increased surface exposed during crushing, is given in Table XI.

TABLE XI.—CRUSHING EFFICIENCIES OF VARIOUS MACHINES<sup>26</sup>

| Plant              | Machine                | Relative<br>surface in<br>feed | Relative<br>surface in<br>product | Index of<br>work done<br>by machine |
|--------------------|------------------------|--------------------------------|-----------------------------------|-------------------------------------|
| Goldfield Con..... | Stamps.....            | 100                            | 14,007                            | 13,907                              |
| Dome.....          | Stamps.....            | 100                            | 18,036                            | 17,936                              |
| Goldfield Con..... | High-speed Chilean ... | 720                            | 27,239                            | 26,519                              |
| Mogul.....         | High-speed Chilean ... | 100                            | 22,835                            | 22,735                              |
| Gold Belt.....     | Slow-speed Chilean ... | 100                            | 32,913                            | 32,813                              |
| Sta. Elena.....    | Slow-speed Chilean ... | 75                             | 35,640                            | 35,565                              |
| La Union.....      | Slow-speed Chilean ... | 100                            | 37,140                            | 37,040                              |
| Llano.....         | Slow-speed Chilean ... | 100                            | 33,108                            | 33,008                              |
| Bolivia.....       | Wheeler pan.....       | 18,363                         | 36,678                            | 18,315                              |

**Rittinger's Law** was disproved by Van Reytt as a result of actual demonstration. The tests made showed that the ratio of work done to increased surface is fairly constant with coarse sizes, but with fine sizes the increase of surface is much more rapid than the work required to produce it.

**Kick's Law** states that the work of crushing is proportional to the reduction in volume resulting. An elaboration of this definition is as follows: The energy required for producing analogous changes of configuration of geometrically similar bodies of equal technological state varies as the volumes or weights of these bodies. Stadler's suggestions for the adaptation of this law to comparative efficiency estimations are as follows:

(a) Classification into grades on the basis of volume or weight.

(b) By reducing the cube of the unit successively to one-half its volume, and assuming these fractures to be again of cubical shape, each size of this series of theoretical cubes obtained represents a grade of a reduction scale of the ratio  $\sqrt[3]{2}$ .

(c) If to each of these grades is given an ordinal number, beginning with 0 as representing the unit of 1-in. cube, then Table XII gives figures to determine the values of the data for the series of the theoretical cubes.

(d) By taking the sides of this series of cubes as clear-mesh apertures of a set of screens it is admissible to assume that the functions of the irregularly shaped average particles, determined by two successive screens, vary in the same ratio as the grades of the theoretical cubes.

**To Obtain the Mechanical Value of a Mixed Product**, for comparative purposes, it is necessary to multiply the screen percentages by the number of the energy units of the respective grades and add the products.

The **Relative Mechanical Efficiency** of two machines or of the same machine operating under different conditions may be obtained by dividing the total work done in each instance, as estimated by the energy-unit system, by any convenient unit of energy such as horsepower consumed. The useful work done by the machine may be estimated from the difference between

TABLE XII.—STADLER'S STANDARD GRADES<sup>86</sup>

| Ordinal number or<br>mechanical value<br>Energy Units | Mesh aperture<br>(= length of side of theoretical cubes) |         |
|-------------------------------------------------------|----------------------------------------------------------|---------|
|                                                       | In.                                                      | Mm.     |
| 30                                                    | 0.00098                                                  | 0.02480 |
| 29                                                    | 0.00123                                                  | 0.03125 |
| 28                                                    | 0.00155                                                  | 0.03937 |
| 27                                                    | 0.00195                                                  | 0.04961 |
| 26                                                    | 0.00246                                                  | 0.06250 |
| 25                                                    | 0.00310                                                  | 0.07875 |
| 24                                                    | 0.00391                                                  | 0.09922 |
| 23                                                    | 0.00492                                                  | 0.1250  |
| 22                                                    | 0.00620                                                  | 0.15750 |
| 21                                                    | 0.00781                                                  | 0.19844 |
| 20                                                    | 0.00984                                                  | 0.250   |
| 19                                                    | 0.01240                                                  | 0.3150  |
| 18                                                    | 0.01562                                                  | 0.39688 |
| 17                                                    | 0.01969                                                  | 0.50    |
| 16                                                    | 0.0248                                                   | 0.630   |
| 15                                                    | 0.03125                                                  | 0.7938  |
| 14                                                    | 0.03937                                                  | 1.0     |
| 13                                                    | 0.04961                                                  | 1.260   |
| 12                                                    | 0.06250                                                  | 1.5875  |
| 11                                                    | 0.07875                                                  | 2.0     |
| 10                                                    | 0.09922                                                  | 2.520   |
| 9                                                     | 0.1250                                                   | 3.1750  |
| 8                                                     | 0.15750                                                  | 4.0003  |
| 7                                                     | 0.19850                                                  | 5.040   |
| 6                                                     | 0.250                                                    | 6.350   |
| 5                                                     | 0.3150                                                   | 8.0005  |
| 4                                                     | 0.39690                                                  | 10.080  |
| 3                                                     | 0.50                                                     | 12.70   |
| 2                                                     | 0.630                                                    | 16.0    |
| 1                                                     | 0.79370                                                  | 20.160  |
| 0                                                     | 1.0                                                      | 25.4    |



the mechanical values of samples from feed and discharge. An example of this method is given in Table XIII. In this case a comparison was being made between the operation of four Nissen stamps and two five-stamp mills. The drop in each case, both with regard to height and frequency, was identical, and the unit of energy was therefore based on effective weight of stamp. The feed in each case was also identical and was assumed to have a relative mechanical value of zero in comparison with the crushed product.

TABLE XIII.—EXAMPLE OF METHOD OF COMPUTING RELATIVE MECHANICAL EFFICIENCY OF CRUSHING MACHINES<sup>27</sup>

(Based on Kick's Law)

| Screening                          |      |               | Four Nissen stamps                                      |                    | Two 5-stamp mills                                      |                    |  |
|------------------------------------|------|---------------|---------------------------------------------------------|--------------------|--------------------------------------------------------|--------------------|--|
| Aperture width, in.                | Mesh | Approx. E. U. | Grading, per cent.                                      | Mech. value, E. U. | Grading, per cent.                                     | Mech. value, E. U. |  |
| 0.159                              | + 5  | 9             | 19.80                                                   | 1.782              | 14.8                                                   | 1.332              |  |
| 0.097                              | + 8  | 11            | 10.75                                                   | 1.183              | 11.28                                                  | 1.241              |  |
| 0.060                              | + 12 | 13            | 9.30                                                    | 1.209              | 10.59                                                  | 1.377              |  |
| 0.034                              | + 20 | 15            | 10.04                                                   | 1.506              | 10.57                                                  | 1.586              |  |
| 0.0198                             | + 30 | 17            | 7.92                                                    | 1.346              | 8.50                                                   | 1.445              |  |
| 0.0110                             | + 50 | 19            | 8.73                                                    | 1.659              | 8.86                                                   | 1.683              |  |
| 0.0068                             | + 80 | 21            | 10.17                                                   | 2.136              | 11.48                                                  | 2.411              |  |
| 0.00433                            | +120 | 24            | 4.71                                                    | 1.130              | 5.38                                                   | 1.291              |  |
| 0.0030                             | +200 |               |                                                         |                    |                                                        |                    |  |
|                                    | -200 | 28            | 18.58                                                   | 5.202              | 18.36                                                  | 5.141              |  |
|                                    |      |               | 100.00                                                  | 17.153             | 99.82                                                  | 17.507             |  |
| Duty per stamp per 24 hours....    |      |               | 27.72 tons                                              |                    | 19.9 tons                                              |                    |  |
| Weight of stamp.....               |      |               | 1927 lb.                                                |                    | 1860 lb.                                               |                    |  |
| Relative mechanical efficiency.... |      |               | $\frac{17.153 \text{ E. U.} \times 27.72}{1927} = 0.25$ |                    | $\frac{17.507 \text{ E. U.} \times 19.9}{1860} = 0.19$ |                    |  |

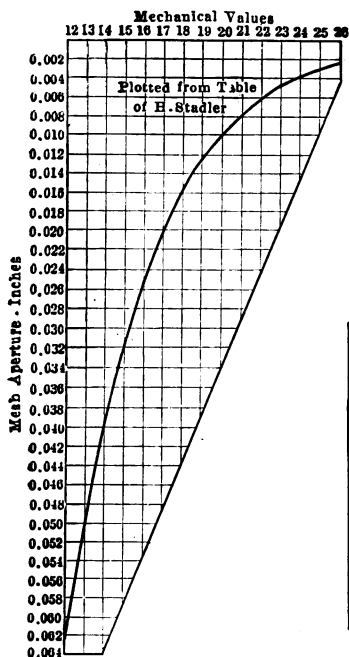
**Approximate Mechanical Values** corresponding to any size of screen aperture may be found from Fig. 37. The top figures (12-26) represent the energy units. Screen aperture widths are given in the left-hand column. The junction of the horizontal

TABLE XIV.—CONSTANTS FOR TYLER SCREEN-SCALE SIEVES\*  
(Graded by Aperture Widths)

| Apertures |              | Average diameter of product |              | Volumes        |                   | Area of fracture |                    | Number of pieces from unit | Energy number, Stadler |
|-----------|--------------|-----------------------------|--------------|----------------|-------------------|------------------|--------------------|----------------------------|------------------------|
| Inches    | Milli-meters | Inches                      | Milli-meters | Cubic inches   | Cubic millimeters | Square inches    | Square millimeters |                            |                        |
| 1.0550    | 26.67        | 0.896                       | 22.76        | 0.71932        | 11,790.0          | 0.0              | 0.0                | 1.0                        | 0                      |
| 0.742     | 18.85        | 0.634                       | 16.09        | 0.25484        | 4,165.5           | 0.99529          | 642.1              | 2.8826                     | 1                      |
| 0.525     | 13.33        | 0.448                       | 11.377       | 0.089915       | 1,472.6           | 2.4085           | 1,553.8            | 8.0000                     | 2                      |
| 0.371     | 9.423        | 0.317                       | 8.052        | 0.031855       | 522.05            | 4.399            | 2,838.0            | 22.581                     | 3                      |
| 0.263     | 6.690        | 0.224                       | 5.690        | 0.011239       | 184.22            | 7.2253           | 4,661.4            | 64.00                      | 4                      |
| 0.185     | 4.699        | 0.158                       | 4.013        | 0.0039443      | 64.626            | 11.280           | 7,277.2            | 182.37                     | 5                      |
| 0.131     | 3.327        | 0.112                       | 2.845        | 0.0014049      | 23.028            | 16.859           | 10,877.0           | 512.0                      | 6                      |
| 0.093     | 2.362        | 0.079                       | 2.014        | 0.00049304     | 8.1692            | 24.908           | 16,069.0           | 1,459.9                    | 7                      |
| 0.065     | 1.666        | 0.056                       | 1.422        | 0.00017562     | 2.8754            | 36.126           | 23,307.0           | 4,096.0                    | 8                      |
| 0.046     | 1.178        | 0.0394                      | 1.000        | 0.000061163    | 1.0000            | 52.362           | 33,781.0           | 11,761.0                   | 9                      |
| 0.0328    | 0.833        | 0.0280                      | 0.711        | 0.000021952    | 0.35943           | 74.662           | 48,167.0           | 32,768.0                   | 10                     |
| 0.0232    | 0.589        | 0.0198                      | 0.503        | 0.0000077624   | 0.12726           | 106.58           | 68,759.0           | 92,668.0                   | 11                     |
| 0.0164    | 0.417        | 0.0140                      | 0.356        | 0.000002744    | 0.045118          | 151.73           | 97,889.0           | 262,140.0                  | 12                     |
| 0.0116    | 0.295        | 0.0099                      | 0.252        | 0.00000097030  | 0.016003          | 215.57           | 139,070.0          | 741,340.0                  | 13                     |
| 0.0082    | 0.208        | 0.0070                      | 0.178        | 0.000000343    | 0.0056398         | 305.87           | 197,330.0          | 2,097,200.0                | 14                     |
| 0.0058    | 0.147        | 0.0050                      | 0.126        | 0.000000125    | 0.0020004         | 429.19           | 276,880.0          | 5,754,600.0                | 15                     |
| 0.0041    | 0.104        | 0.0035                      | 0.089        | 0.000000042875 | 0.00070497        | 614.15           | 396,220.0          | 16,777,000.0               | 16                     |
| 0.0029    | 0.074        | 0.0022                      | 0.056        | 0.000000010648 | 0.00017562        | 978.49           | 631,260.0          | 67,555,000.0               | 17.34                  |
| 0.0014*   | 0.037        |                             |              |                |                   |                  |                    |                            |                        |

\* Assumed.

line from the given screen aperture with the curve shown will give a point vertically below the required mechanical value.



| Mechanical<br>Values<br>E. U. | Aperture       |                  |
|-------------------------------|----------------|------------------|
|                               | Width:<br>Inch | Mesh:            |
| 1                             | 0.7937         | $\frac{3}{4}$ "  |
| 2                             | 0.63           | $\frac{1}{2}$ "  |
| 3                             | 0.50           | $\frac{3}{8}$ "  |
| 4                             | 0.3909         | $\frac{1}{2}$ "  |
| 5                             | 0.315          | $\frac{5}{16}$ " |
| 6                             | 0.250          | $\frac{1}{4}$ "  |
| 7                             | 0.1985         | 3.5              |
| 8                             | 0.1575         | 4                |
| 9                             | 0.125          | 6                |
| 10                            | 0.09022        | 8                |
| 11                            | 0.07875        | 10               |

FIG. 37.—Stadler energy-unit curve.<sup>28</sup>

A Table of Constants for Tyler Standard Sieves calculated on the basis of average sizes of successive screened products rather than aperture sizes, is given in Table XIV. The figures are, therefore, based on average size of product through the coarser sieve on the next finer.

## SECTION V

### ROASTING

**Roasting of Metalliferous Ores** is carried out for the purpose of removing certain elements which would interfere with subsequent treatment. Copper, lead, zinc, and gold ores and concentrates are roasted to remove sulphur and in order to make the material amenable to smelting operations, and for the purpose of removing certain volatile refractory metals, such as arsenic and bismuth. Gold ores are roasted as a preliminary to cyanide treatment in order to eliminate the possible action of interfering elements, to reduce tonnage, and to facilitate subsequent grinding. The freeing of gold from encasing pyrite, by roasting, is also an important factor in the amalgamation treatment of a complex ore.

**Heap Roasting** is a simple process in which a large cone of coarse ore is piled over a stack of wood fuel. The latter when ignited supplies the necessary heat and draught, and the roasting proceeds without additional fuel provided the ore carries sufficient sulphur to maintain combustion.

A chart for the rapid **Conversion of Fahrenheit into Centigrade Temperatures**, or vice versa, is given in Table XV.

The **Edwards Furnace** (Fig. 38), designed in Australia, and used with success in the roasting of the sulpho-telluride ores at Kalgoorlie, is a reverberatory furnace of the straight-line, single-hearth type. There are two fireplaces. The rabblers and rabble spindles are water cooled at the front end of the furnace. These are of the usual revolving type and driven by suitable gearing from the top of the furnace. Inclination of the furnace from the horizontal will depend on the character of the ore and the time required for roasting. Average practice would indicate a fall of about 8 in. from feed to discharge, a distance of 70 ft.

TABLE XV.—CONVERSION SCALE FOR CENTIGRADE AND FAHRENHEIT TEMPERATURE <sup>30</sup>

| °C    | °F    | °C  | °F    | °C  | °F    | °C   | °F    | °C    | °F    |
|-------|-------|-----|-------|-----|-------|------|-------|-------|-------|
| 300   | 572   | 600 | 1112  | 900 | 1652  | 1200 | 2192  | 1500  | 2732  |
| 90    | 60    | 90  | 100   | 90  | 40    | 90   | 80    | 90    | 20    |
| 80    | 50    | 80  | 90    | 80  | 30    | 80   | 70    | 80    | 10    |
| 70    | 40    | 70  | 80    | 70  | 20    | 80   | 60    | 80    | 2700  |
| 60    | 30    | 70  | 70    | 70  | 10    | 70   | 50    | 70    | 90    |
| 50    | 20    | 60  | 60    | 60  | 0     | 60   | 40    | 70    | 80    |
| 40    | 10    | 60  | 50    | 60  | -10   | 60   | 30    | 60    | 70    |
| 30    | 0     | 50  | 40    | 50  | -20   | 50   | 20    | 60    | 60    |
| 20    | -10   | 50  | 30    | 50  | -30   | 50   | 10    | 50    | 50    |
| 10    | -20   | 40  | 20    | 40  | -40   | 40   | 0     | 50    | 40    |
| 0     | -30   | 40  | 10    | 40  | -50   | 40   | -10   | 40    | 30    |
| -10   | -40   | 30  | 0     | 30  | -60   | 30   | -20   | 40    | 20    |
| -20   | -50   | 30  | -10   | 30  | -70   | 30   | -30   | 30    | 10    |
| -30   | -60   | 20  | -20   | 20  | -80   | 20   | -40   | 20    | 0     |
| -40   | -70   | 20  | -30   | 20  | -90   | 20   | -50   | 10    | -10   |
| -50   | -80   | 10  | -40   | 10  | -100  | 10   | -60   | 0     | -20   |
| -60   | -90   | 10  | -50   | 10  | -110  | 10   | -70   | -10   | -30   |
| -70   | -100  | 0   | -60   | 0   | -120  | 0    | -80   | -20   | -40   |
| -80   | -110  | 0   | -70   | 0   | -130  | 0    | -90   | -30   | -50   |
| -90   | -120  | 0   | -80   | 0   | -140  | 0    | -100  | -40   | -60   |
| -100  | -130  | 0   | -90   | 0   | -150  | 0    | -110  | -50   | -70   |
| -110  | -140  | 0   | -100  | 0   | -160  | 0    | -120  | -60   | -80   |
| -120  | -150  | 0   | -110  | 0   | -170  | 0    | -130  | -70   | -90   |
| -130  | -160  | 0   | -120  | 0   | -180  | 0    | -140  | -80   | -100  |
| -140  | -170  | 0   | -130  | 0   | -190  | 0    | -150  | -90   | -110  |
| -150  | -180  | 0   | -140  | 0   | -200  | 0    | -160  | -100  | -120  |
| -160  | -190  | 0   | -150  | 0   | -210  | 0    | -170  | -110  | -130  |
| -170  | -200  | 0   | -160  | 0   | -220  | 0    | -180  | -120  | -140  |
| -180  | -210  | 0   | -170  | 0   | -230  | 0    | -190  | -130  | -150  |
| -190  | -220  | 0   | -180  | 0   | -240  | 0    | -200  | -140  | -160  |
| -200  | -230  | 0   | -190  | 0   | -250  | 0    | -210  | -150  | -170  |
| -210  | -240  | 0   | -200  | 0   | -260  | 0    | -220  | -160  | -180  |
| -220  | -250  | 0   | -210  | 0   | -270  | 0    | -230  | -170  | -190  |
| -230  | -260  | 0   | -220  | 0   | -280  | 0    | -240  | -180  | -200  |
| -240  | -270  | 0   | -230  | 0   | -290  | 0    | -250  | -190  | -210  |
| -250  | -280  | 0   | -240  | 0   | -300  | 0    | -260  | -200  | -220  |
| -260  | -290  | 0   | -250  | 0   | -310  | 0    | -270  | -210  | -230  |
| -270  | -300  | 0   | -260  | 0   | -320  | 0    | -280  | -220  | -240  |
| -280  | -310  | 0   | -270  | 0   | -330  | 0    | -290  | -230  | -250  |
| -290  | -320  | 0   | -280  | 0   | -340  | 0    | -300  | -240  | -260  |
| -300  | -330  | 0   | -290  | 0   | -350  | 0    | -310  | -250  | -270  |
| -310  | -340  | 0   | -300  | 0   | -360  | 0    | -320  | -260  | -280  |
| -320  | -350  | 0   | -310  | 0   | -370  | 0    | -330  | -270  | -290  |
| -330  | -360  | 0   | -320  | 0   | -380  | 0    | -340  | -280  | -300  |
| -340  | -370  | 0   | -330  | 0   | -390  | 0    | -350  | -290  | -310  |
| -350  | -380  | 0   | -340  | 0   | -400  | 0    | -360  | -300  | -320  |
| -360  | -390  | 0   | -350  | 0   | -410  | 0    | -370  | -310  | -330  |
| -370  | -400  | 0   | -360  | 0   | -420  | 0    | -380  | -320  | -340  |
| -380  | -410  | 0   | -370  | 0   | -430  | 0    | -390  | -330  | -350  |
| -390  | -420  | 0   | -380  | 0   | -440  | 0    | -400  | -340  | -360  |
| -400  | -430  | 0   | -390  | 0   | -450  | 0    | -410  | -350  | -370  |
| -410  | -440  | 0   | -400  | 0   | -460  | 0    | -420  | -360  | -380  |
| -420  | -450  | 0   | -410  | 0   | -470  | 0    | -430  | -370  | -390  |
| -430  | -460  | 0   | -420  | 0   | -480  | 0    | -440  | -380  | -400  |
| -440  | -470  | 0   | -430  | 0   | -490  | 0    | -450  | -390  | -410  |
| -450  | -480  | 0   | -440  | 0   | -500  | 0    | -460  | -400  | -420  |
| -460  | -490  | 0   | -450  | 0   | -510  | 0    | -470  | -410  | -430  |
| -470  | -500  | 0   | -460  | 0   | -520  | 0    | -480  | -420  | -440  |
| -480  | -510  | 0   | -470  | 0   | -530  | 0    | -490  | -430  | -450  |
| -490  | -520  | 0   | -480  | 0   | -540  | 0    | -500  | -440  | -460  |
| -500  | -530  | 0   | -490  | 0   | -550  | 0    | -510  | -450  | -470  |
| -510  | -540  | 0   | -500  | 0   | -560  | 0    | -520  | -460  | -480  |
| -520  | -550  | 0   | -510  | 0   | -570  | 0    | -530  | -470  | -490  |
| -530  | -560  | 0   | -520  | 0   | -580  | 0    | -540  | -480  | -500  |
| -540  | -570  | 0   | -530  | 0   | -590  | 0    | -550  | -490  | -510  |
| -550  | -580  | 0   | -540  | 0   | -600  | 0    | -560  | -500  | -520  |
| -560  | -590  | 0   | -550  | 0   | -610  | 0    | -570  | -510  | -530  |
| -570  | -600  | 0   | -560  | 0   | -620  | 0    | -580  | -520  | -540  |
| -580  | -610  | 0   | -570  | 0   | -630  | 0    | -590  | -530  | -550  |
| -590  | -620  | 0   | -580  | 0   | -640  | 0    | -600  | -540  | -560  |
| -600  | -630  | 0   | -590  | 0   | -650  | 0    | -610  | -550  | -570  |
| -610  | -640  | 0   | -600  | 0   | -660  | 0    | -620  | -560  | -580  |
| -620  | -650  | 0   | -610  | 0   | -670  | 0    | -630  | -570  | -590  |
| -630  | -660  | 0   | -620  | 0   | -680  | 0    | -640  | -580  | -600  |
| -640  | -670  | 0   | -630  | 0   | -690  | 0    | -650  | -590  | -610  |
| -650  | -680  | 0   | -640  | 0   | -700  | 0    | -660  | -600  | -620  |
| -660  | -690  | 0   | -650  | 0   | -710  | 0    | -670  | -610  | -630  |
| -670  | -700  | 0   | -660  | 0   | -720  | 0    | -680  | -620  | -640  |
| -680  | -710  | 0   | -670  | 0   | -730  | 0    | -690  | -630  | -650  |
| -690  | -720  | 0   | -680  | 0   | -740  | 0    | -700  | -640  | -660  |
| -700  | -730  | 0   | -690  | 0   | -750  | 0    | -710  | -650  | -670  |
| -710  | -740  | 0   | -700  | 0   | -760  | 0    | -720  | -660  | -680  |
| -720  | -750  | 0   | -710  | 0   | -770  | 0    | -730  | -670  | -690  |
| -730  | -760  | 0   | -720  | 0   | -780  | 0    | -740  | -680  | -700  |
| -740  | -770  | 0   | -730  | 0   | -790  | 0    | -750  | -690  | -710  |
| -750  | -780  | 0   | -740  | 0   | -800  | 0    | -760  | -700  | -720  |
| -760  | -790  | 0   | -750  | 0   | -810  | 0    | -770  | -710  | -730  |
| -770  | -800  | 0   | -760  | 0   | -820  | 0    | -780  | -720  | -740  |
| -780  | -810  | 0   | -770  | 0   | -830  | 0    | -790  | -730  | -750  |
| -790  | -820  | 0   | -780  | 0   | -840  | 0    | -800  | -740  | -760  |
| -800  | -830  | 0   | -790  | 0   | -850  | 0    | -810  | -750  | -770  |
| -810  | -840  | 0   | -800  | 0   | -860  | 0    | -820  | -760  | -780  |
| -820  | -850  | 0   | -810  | 0   | -870  | 0    | -830  | -770  | -790  |
| -830  | -860  | 0   | -820  | 0   | -880  | 0    | -840  | -780  | -800  |
| -840  | -870  | 0   | -830  | 0   | -890  | 0    | -850  | -790  | -810  |
| -850  | -880  | 0   | -840  | 0   | -900  | 0    | -860  | -800  | -820  |
| -860  | -890  | 0   | -850  | 0   | -910  | 0    | -870  | -810  | -830  |
| -870  | -900  | 0   | -860  | 0   | -920  | 0    | -880  | -820  | -840  |
| -880  | -910  | 0   | -870  | 0   | -930  | 0    | -890  | -830  | -850  |
| -890  | -920  | 0   | -880  | 0   | -940  | 0    | -900  | -840  | -860  |
| -900  | -930  | 0   | -890  | 0   | -950  | 0    | -910  | -850  | -870  |
| -910  | -940  | 0   | -900  | 0   | -960  | 0    | -920  | -860  | -880  |
| -920  | -950  | 0   | -910  | 0   | -970  | 0    | -930  | -870  | -890  |
| -930  | -960  | 0   | -920  | 0   | -980  | 0    | -940  | -880  | -900  |
| -940  | -970  | 0   | -930  | 0   | -990  | 0    | -950  | -890  | -910  |
| -950  | -980  | 0   | -940  | 0   | -1000 | 0    | -960  | -900  | -920  |
| -960  | -990  | 0   | -950  | 0   | -1010 | 0    | -970  | -910  | -930  |
| -970  | -1000 | 0   | -960  | 0   | -1020 | 0    | -980  | -920  | -940  |
| -980  | -1010 | 0   | -970  | 0   | -1030 | 0    | -990  | -930  | -950  |
| -990  | -1020 | 0   | -980  | 0   | -1040 | 0    | -1000 | -940  | -960  |
| -1000 | -1030 | 0   | -990  | 0   | -1050 | 0    | -1010 | -950  | -970  |
| -1010 | -1040 | 0   | -1000 | 0   | -1060 | 0    | -1020 | -960  | -980  |
| -1020 | -1050 | 0   | -1010 | 0   | -1070 | 0    | -1030 | -970  | -990  |
| -1030 | -1060 | 0   | -1020 | 0   | -1080 | 0    | -1040 | -980  | -1000 |
| -1040 | -1070 | 0   | -1030 | 0   | -1090 | 0    | -1050 | -990  | -1010 |
| -1050 | -1080 | 0   | -1040 | 0   | -1100 | 0    | -1060 | -1000 | -1020 |
| -1060 | -1090 | 0   | -1050 | 0   | -1110 | 0    | -1070 | -1010 | -1030 |
| -1070 | -1100 | 0   | -1060 | 0   | -1120 | 0    | -1080 | -1020 | -1040 |
| -1080 | -1110 | 0   | -1070 | 0   | -1130 | 0    | -1090 | -1030 | -1050 |
| -1090 | -1120 | 0   | -1080 | 0   | -1140 | 0    | -1100 | -1040 | -1060 |
| -1100 | -1130 | 0   | -1090 | 0   | -1150 | 0    | -1110 | -1050 | -1070 |
| -1110 | -1140 | 0   | -1100 | 0   | -1160 | 0    | -1120 | -1060 | -1080 |
| -1120 | -1150 | 0   | -1110 | 0   | -1170 | 0    | -1130 | -1070 | -1090 |
| -1130 | -1160 | 0   | -1120 | 0   | -1180 | 0    | -1140 | -1080 | -1100 |
| -1140 | -1170 | 0   | -1130 | 0   | -1190 | 0    | -1150 | -1090 | -1110 |
| -1150 | -1180 | 0   | -1140 | 0   | -1200 | 0    | -1160 | -1100 | -1120 |
| -1160 | -1190 | 0   | -1150 | 0   | -1210 | 0    | -1170 | -1110 | -1130 |
| -1170 | -1200 | 0   | -1160 | 0   | -1220 | 0    | -1180 | -1120 | -1140 |
| -1180 | -1210 | 0   | -1170 | 0   | -1230 | 0    | -1190 | -1130 | -1150 |
| -1190 | -1220 | 0   | -1180 | 0   | -1240 | 0    | -1200 | -1140 | -1160 |
| -1200 | -1230 | 0   | -1190 | 0   | -1250 | 0    | -1210 | -1150 | -1170 |
| -1210 | -1240 | 0   | -1200 | 0   | -1260 | 0    | -1220 | -1160 | -1180 |
| -1220 | -1250 | 0   | -1210 | 0   | -1270 | 0    | -1230 | -1170 | -1190 |
| -1230 | -1260 | 0   | -1220 | 0   | -1280 | 0    | -1240 | -1180 | -1200 |
| -1240 | -1270 | 0   | -1230 | 0   | -1290 | 0    | -1250 | -1190 | -1210 |
| -1250 | -1280 | 0   | -1240 | 0   | -1300 | 0    | -1260 | -1200 | -1220 |
| -1260 | -1290 | 0   | -1250 | 0   | -1310 | 0    | -1270 | -1210 | -1230 |
| -1270 | -1300 | 0   | -1260 | 0   | -1320 | 0    | -1280 | -1220 | -1240 |
| -1280 | -1310 | 0   | -1270 | 0   | -1330 | 0    | -1290 | -1230 | -1250 |
| -1290 | -1320 | 0   | -1280 | 0   | -1340 | 0    | -1300 | -1240 | -1260 |
| -1300 | -1330 | 0   | -1290 | 0   | -1350 | 0    | -1310 | -1250 | -1270 |
| -1310 | -1340 | 0   | -1300 | 0   | -1360 | 0    | -1320 | -1260 | -1280 |
| -1320 | -1350 | 0   | -1310 | 0   | -1370 | 0    | -1330 | -1270 | -1290 |
| -1330 | -1360 | 0   | -1320 | 0   | -1380 | 0    | -1340 | -1280 | -1300 |
| -1340 | -1370 | 0   | -1330 | 0   | -1390 | 0    | -1350 | -1290 | -1310 |
| -1350 | -1380 | 0   | -1340 | 0   | -1400 | 0    | -1360 | -1300 | -1320 |
| -1360 | -1390 | 0   | -1350 | 0   | -1410 | 0    | -1370 | -1310 | -1330 |
| -1370 | -1400 | 0   | -1360 | 0   | -1420 | 0    | -1380 | -1320 | -1340 |
| -1380 | -1410 | 0   | -1370 | 0   | -1430 | 0    | -1390 | -1330 | -1350 |
| -1390 | -1420 | 0   | -1380 | 0   | -     |      |       |       |       |

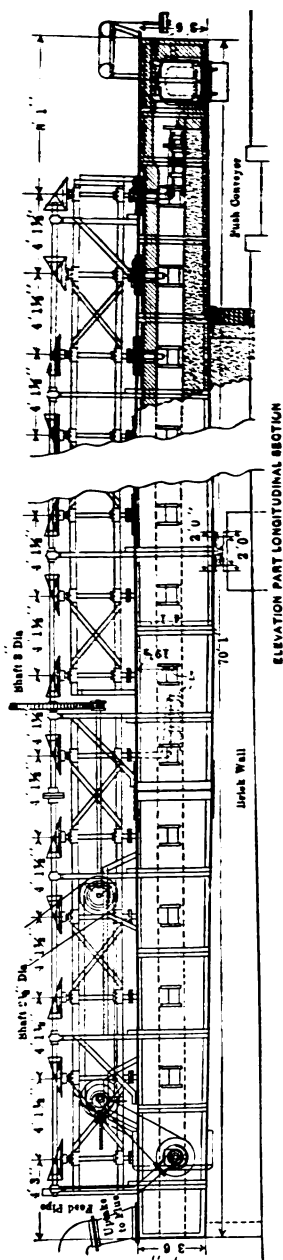


FIG. 38.—Edwards roasting furnace. 7

The **Merton Furnace** (Fig. 39) is a more compact modification of the Edwards type and consists of three superimposed hearths. Effective action occurs as the ore drops through the flame from one hearth to the hearth next below. The rabbles are similar to those used in the Edwards furnace and are water cooled. This furnace is said to have a greater capacity than the Edwards, and involves smaller initial cost.

The **Ropp Furnace** is of the single-hearth, straight-line type in which a rake operates in place of the usual revolving rabbles.

The **Holthoff-Wetthey Furnace** has two hearths, a cooling hearth being arranged below the roasting hearth. The rabbles, consisting of horizontal carriers with a number of blades attached, are driven by chains which are in turn operated by sprocket wheels. The rabble carriers are supported by rollers attached to the chains at each end and operate over the whole width of the hearth.

The **Combination Edwards and Holthoff-Wetthey Furnace** (Fig. 40) designed at the Great Boulder Perseverance Mine, Kalgoorlie, utilizes the rabbling system of the Edwards furnace in the top hearth and the Holthoff-Wetthey system in the lower hearth.

The **Pearce Turret Furnace** (Fig. 41), now largely superseded by the Edwards, consists of a circular

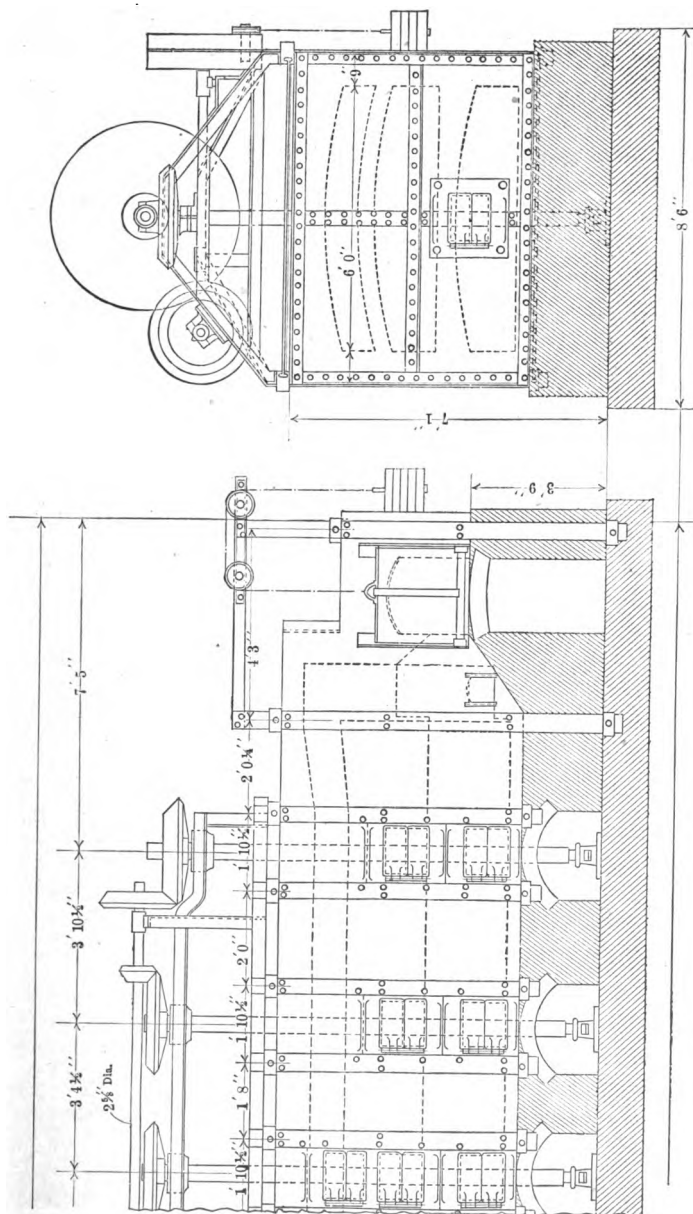


Fig. 39.—Merton roasting furnace (feed end).<sup>7</sup>

reverberatory hearth, single or superimposed, interrupted by a discharge hopper. Rabbling is done by means of rotating water-cooled rabble arms, to which are attached solid plate-steel or bar-iron rabbles.

The **Macdougall Furnace** consists of a number of circular hearths contained in a cylinder or tower. Rabbling is effected by means of a central shaft to which are connected a number of rabbles operating over the ore in each hearth. The ore is rabbled from centre to circumference in one hearth and from circumference to centre in the hearth below. In the former case the ore

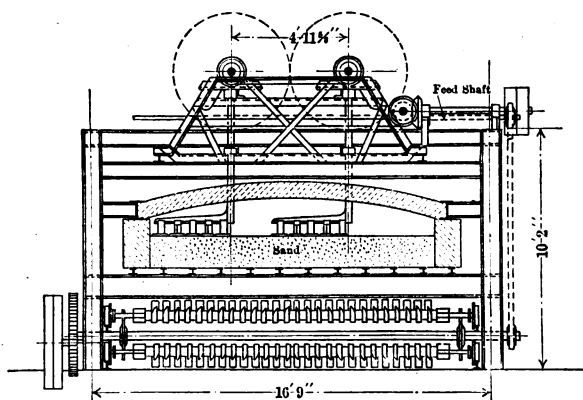
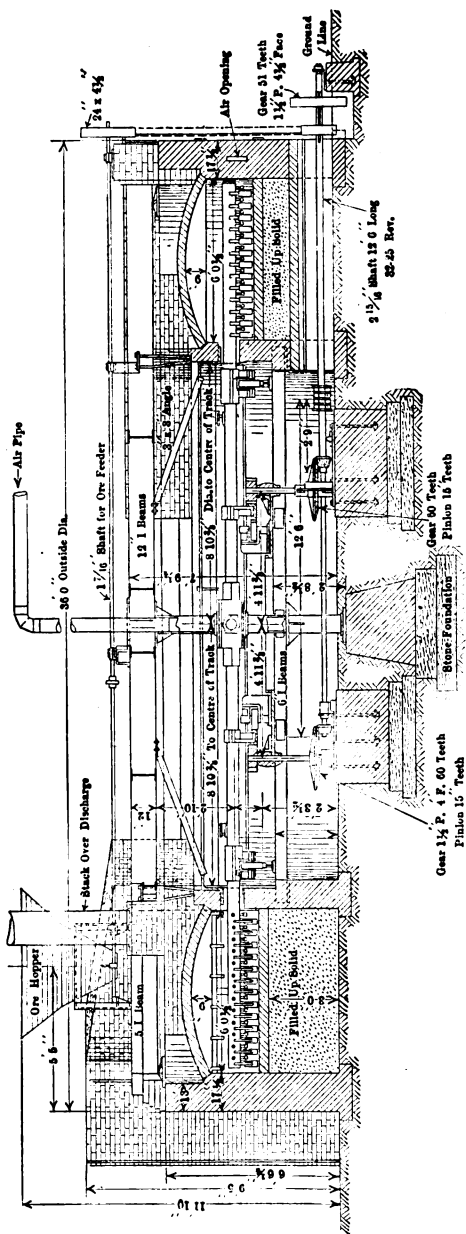


FIG. 40.—Edwards & Holthoff-Wetthey furnace.<sup>7</sup>

drops through a pass near the circumference and in the latter case near the centre. The roasting action is materially helped by the direct exposure to the flame during transit from the hearth to the one below. The ore is fed through the roof. Capacity averages about 25 sq. ft. hearth area per ton roasted per 24 hours.

The **Herreshoff Roasting Furnace** (Fig. 42), a modification of the Macdougall roaster, has air-cooled rabbles. The utilization of the heated air in the form of draught has been found to result in an economy in fuel consumption and permits the roasting of a concentrate lower in sulphur content than would otherwise be possible.





**FIG. 41.—Single hearth Pearce turret furnace**

In the **O'Brien Furnace** (Fig. 43) the Macdougall principle is followed, but the central driving shaft is hollow and consists of three compartments. The central compartment serves for

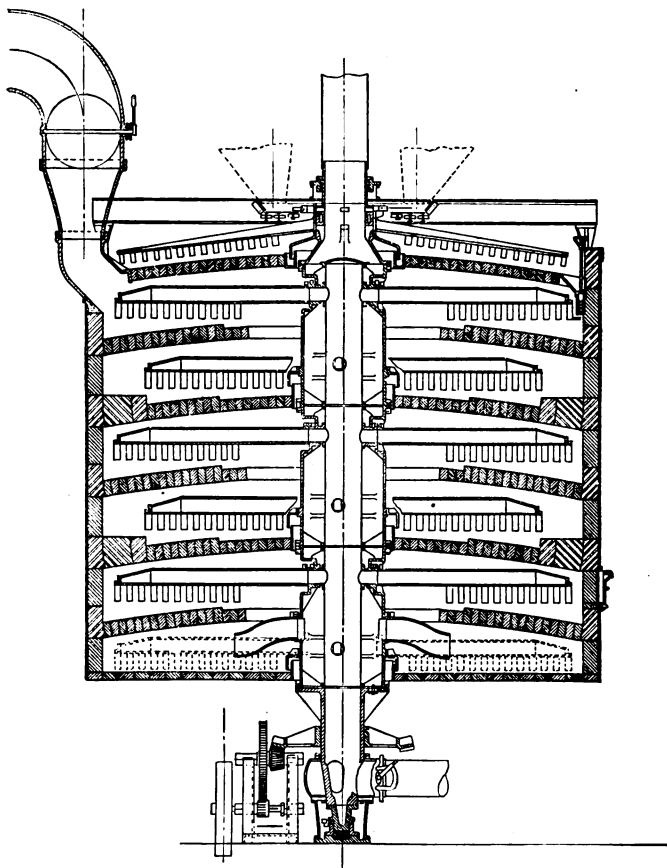


FIG. 42.—Herreshoff roasting furnace.

the passage of cold air to the rabblers and the two others serve as outlets for the hot air. The rabblers are fitted with a division plate placed horizontally. The cold air enters from the shaft and passes under this plate and returns above it to the shaft.

The arms are inserted or removed horizontally, thus insuring space and heat economy and greater capacity.

In the **Wedge Furnace** (Fig. 44) the essential feature is an enlarged central shaft, about 5 ft. in diameter, through which it is possible to remove and replace the rabble arms, and which also facilitates the use of independent air or water connections

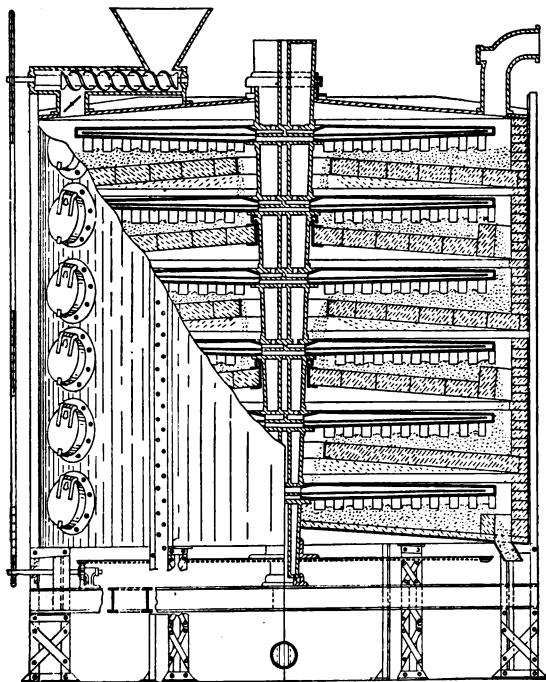


FIG. 43.—P'Brien furnace.

to each arm. Adjustment of practice may be made to suit the requirements of the particular ore being roasted during the operation of the furnace.

In the **Ridge Furnace** (Fig. 45) there are a number of superimposed hearths. The uppermost hearth dries and heats the ore and from there it is fed downward through passes to the

lower hearths, being rabbled en route. The lowest hearth is a cooling hearth where the air required in the furnace is preheated.

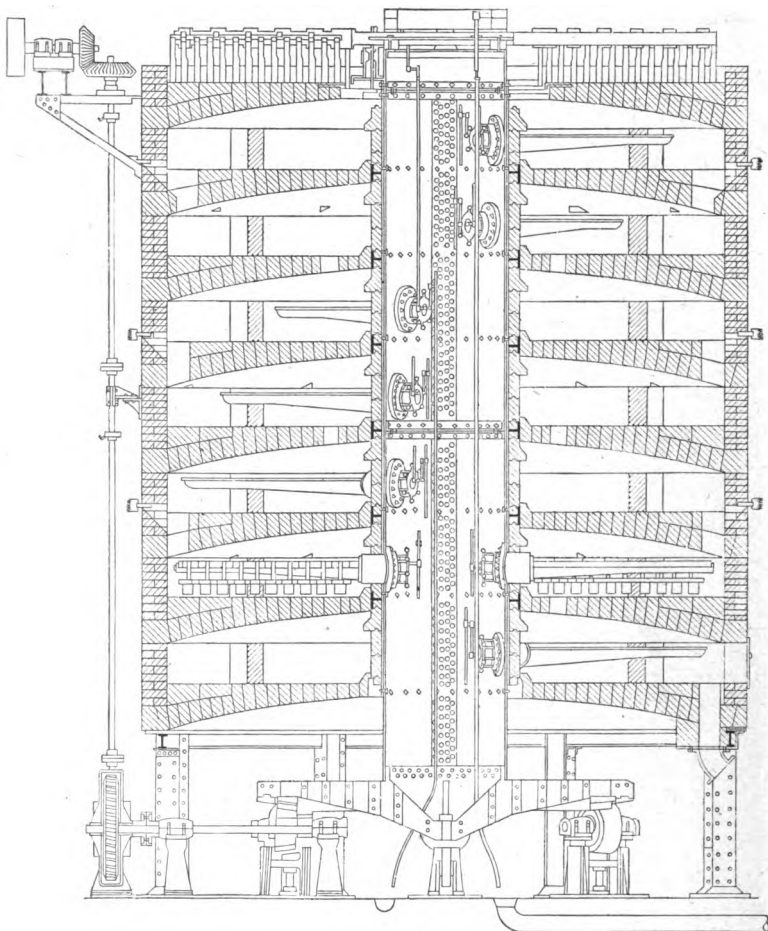


FIG. 44.—Wedge mechanical furnace.

An economy of heat in cooling the ore before it leaves the furnace, and utilizing the heat so recovered, is claimed.

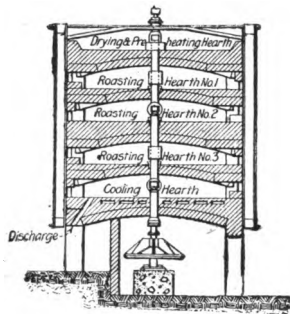


FIG. 45.—Ridge roasting furnace.

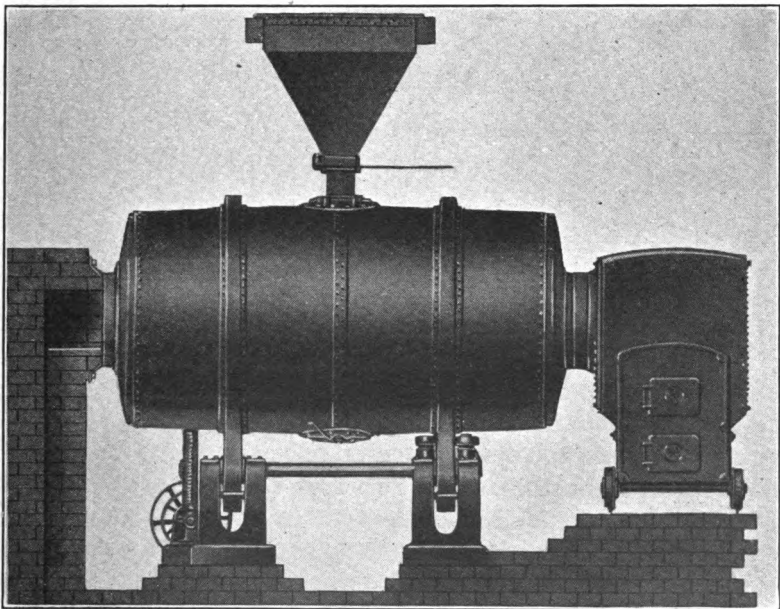


FIG. 46.—Bruckner roasting furnace.

The **Bruckner Roasting Furnace** is of the cylindrical revolving type, and of intermittent operation. The furnace body is supported by double tires and rollers, the latter being operated by means of a shaft driven by worm gear. In the type illustrated (Fig. 46) the fire-box is of the removable type with no fixed connection between it and the furnace.

A **Fine-Ore Feeder** for roasting furnaces is shown in Fig. 47. This consists<sup>7</sup> of a fluted roll operated by a crank and ratchet driven by an eccentric rod off the roasting driving gear. Adjustment is made by altering the throw of the bell crank. The

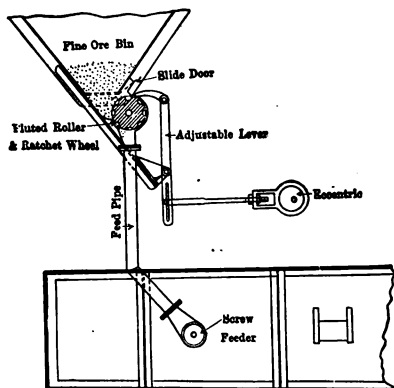


FIG. 47.—Fine-ore roasting furnace feeder.<sup>7</sup>

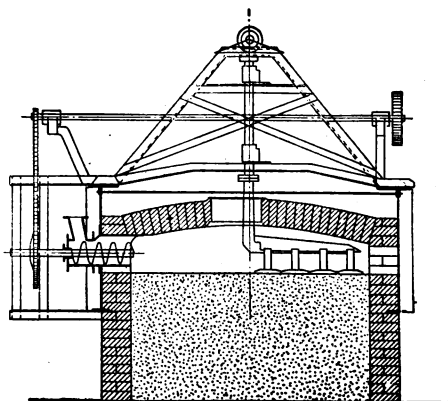


FIG. 48.—Conveyor feeder for furnace.<sup>7</sup>

fluted roll is 11 in. diam. and 14 in. long and has 8 corrugations, each 2 in. in diam. The centres of curvatures of the corrugations are on the circumference of the roll. A cast-iron shell forms the casing to the rolls and is provided with inspection covers to permit the removal of any undesirable material.

**Delivery of Ground Ore into Furnace Chamber<sup>7</sup>** may be effected by means of a short screw conveyor (see Fig. 48) adjusted to deliver well above the maximum requirements. Actual feed amount is controlled by an adjustable device connected with the ore-feeding arrangements.

## SECTION VI

### SCREENING

**Grizzlies** (Fig. 49) are used to classify a coarsely broken or unbroken ore by screening. The screen usually consists of a number of steel bars of tapered section (the thicker edge being toward the ore stream) and spaced according to size and product required. The bars are set at sufficient inclination to permit the ore to traverse the length of the grizzly without need for raking

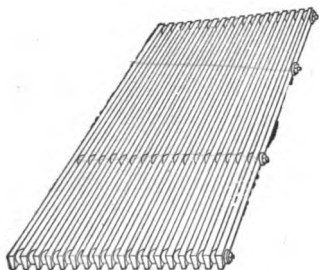
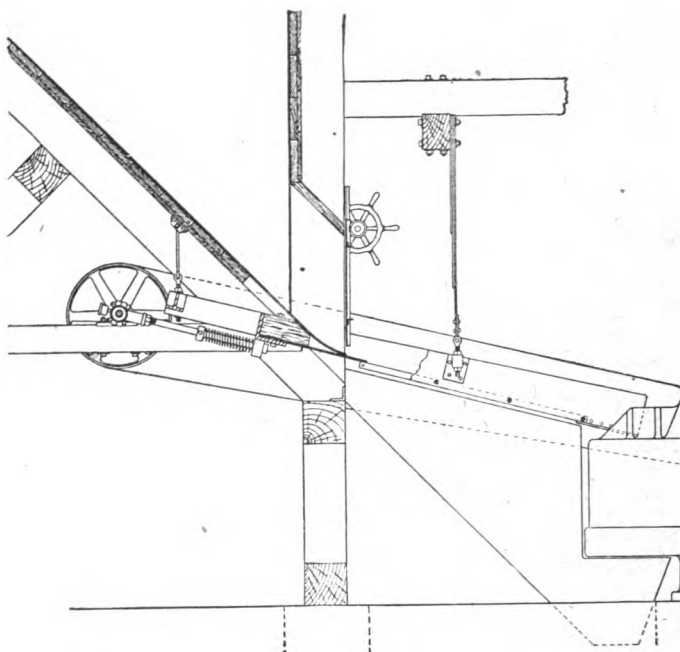
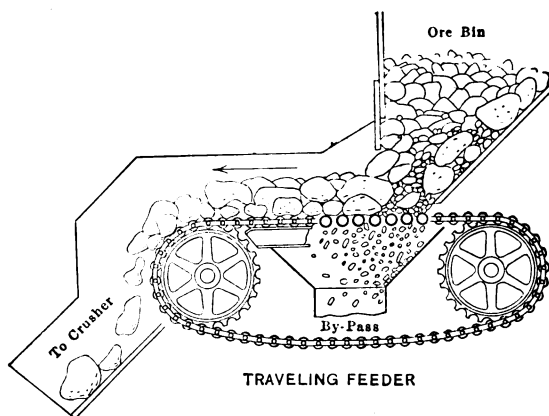


FIG. 49.—Ore grizzly.

or shoveling. They are sometimes placed horizontally in front of the rock breakers and above the ore bins and serve to reduce wear on the shoveling floor. **Shaking Grizzlies** (Fig. 50) have only a limited application and are not widely adopted.

A **Crusher-Feeder** and a **Triple-Screening Grizzly** are shown in Figs. 51 and 52, respectively.

A **Trommel** (Figs. 53 and 54) consists of a cylindrical-, conical-, hexagonal-, or octagonal-shaped screen which is revolved, and is used for washing or classifying ores. Several products of different grades may be obtained by using the trommels in series, by fitting the frame with screen of different-sized apertures, or by con-

FIG. 50.—Shaking grizzly.<sup>12</sup>FIG. 51.—Crusher-feeder grizzly.<sup>14</sup>



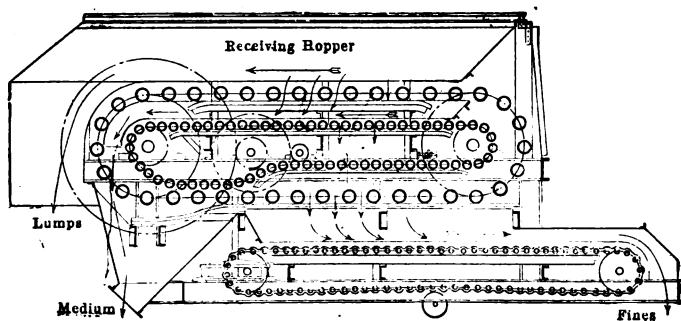


FIG. 52.—Triple screening grizzly.<sup>14</sup>

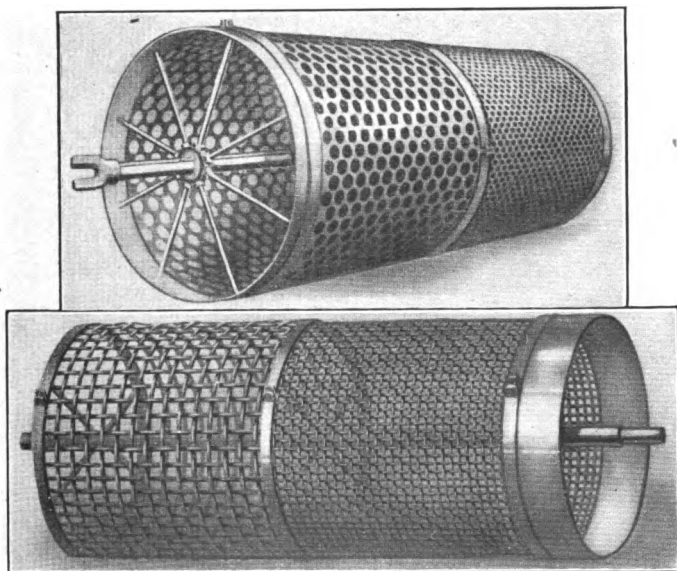


FIG. 53.—Revolving screen.

structing the trommel of several concentric cylinders each of larger diameter and with smaller perforations than the one preceding it.

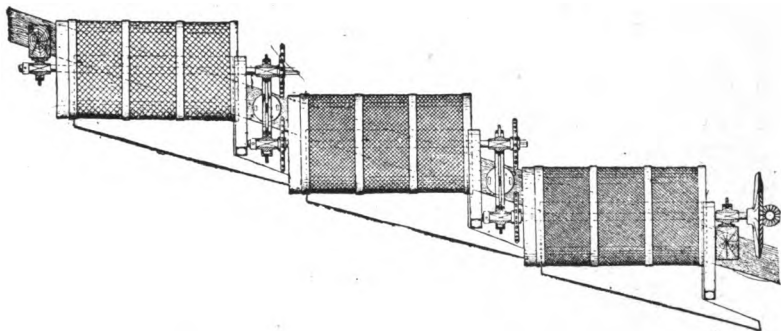


FIG. 54.—Revolving screens operating in series.<sup>19</sup>

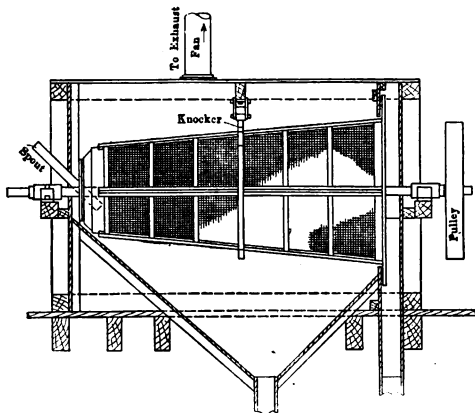


FIG. 55.—Hexagonal revolving screen.<sup>12</sup>

**Hexagonal or Octagonal Revolving Screens** (Fig. 55) insure better sieving as a result of more energetic impact between material and screen. Screen life is proportionately shorter.

**Trommel Perforation** sizes, on account of screen-plate inclination and speed, do not coincide with product sizes. A 1-in. cube will require approximately a  $1\frac{1}{2}$ -in. diameter ring to pass through, and a  $1\frac{3}{4}$ -in. opening to be screened by trommel. A statement of comparative measurements for various sizes is given in Table XVI.

The **Maximum Thickness of Steel Plate** through which it is practicable to punch round or square holes of the diameter

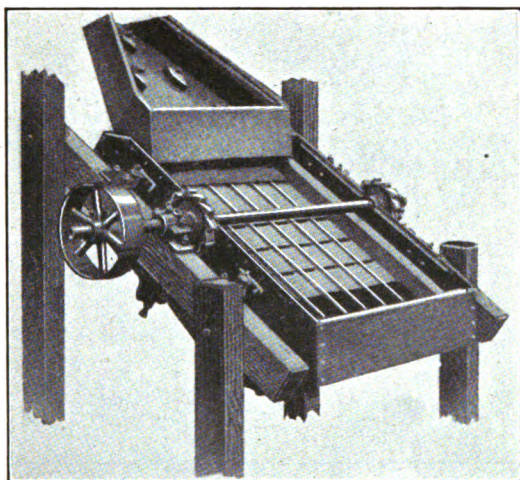


FIG. 56.—Impact screen.<sup>31</sup>

stated is indicated in Table XVII. The figures given are in excess of average requirements.

The **Impact Screen** (Fig. 56) operates by means of a shaft to which two ratchets are attached. The cams force the frame downward against springs, which subsequently carry the frame, on release, outward and upward against the stops. The length of stroke can be regulated, and the impact is such that the entire body of ore is momentarily lifted off the surface of the screen.

TABLE XVI.—SCHEDULE OF RELATIVE SIZES OF STONE AND SCREEN\*

| Size of cube |                  | Size of ring |                  | Size of revolving screen perforation, in. |
|--------------|------------------|--------------|------------------|-------------------------------------------|
| Exact, in.   | Approximate, in. | Exact, in.   | Approximate, in. |                                           |
| 0.144        | $\frac{1}{8}$    | 0.204        | $\frac{3}{16}$   | $\frac{1}{4}$                             |
| 0.216        | $\frac{7}{32}$   | 0.306        | $\frac{5}{16}$   | $\frac{3}{8}$                             |
| 0.289        | $\frac{9}{32}$   | 0.408        | $\frac{3}{8}$    | $\frac{1}{2}$                             |
| 0.361        | $\frac{3}{8}$    | 0.510        | $\frac{1}{2}$    | $\frac{5}{8}$                             |
| 0.433        | $\frac{7}{16}$   | 0.613        | $\frac{5}{8}$    | $\frac{3}{4}$                             |
| 0.505        | $\frac{1}{2}$    | 0.715        | $\frac{3}{4}$    | $\frac{7}{8}$                             |
| 0.578        | $\frac{9}{16}$   | 0.816        | $1\frac{1}{16}$  | 1                                         |
| 0.720        | $\frac{3}{4}$    | 1.02         | 1                | $1\frac{1}{4}$                            |
| 0.865        | $\frac{7}{8}$    | 1.23         | $1\frac{1}{4}$   | $1\frac{1}{2}$                            |
| 1.01         | 1                | 1.43         | $1\frac{7}{16}$  | $1\frac{3}{4}$                            |
| 1.15         | $1\frac{1}{8}$   | 1.63         | $1\frac{5}{8}$   | 2                                         |
| 1.30         | $1\frac{1}{4}$   | 1.84         | $1\frac{7}{8}$   | $2\frac{1}{4}$                            |
| 1.44         | $1\frac{1}{2}$   | 2.04         | 2                | $2\frac{1}{2}$                            |
| 1.73         | $1\frac{3}{4}$   | 2.45         | $2\frac{1}{2}$   | 3                                         |
| 2.02         | 2                | 2.86         | $2\frac{7}{8}$   | $3\frac{1}{2}$                            |
| 2.31         | $2\frac{1}{4}$   | 3.26         | $3\frac{1}{4}$   | 4                                         |
| 2.60         | $2\frac{5}{8}$   | 3.67         | $3\frac{5}{8}$   | $4\frac{1}{2}$                            |
| 2.88         | $2\frac{7}{8}$   | 4.08         | 4                | 5                                         |
| 3.46         | $3\frac{1}{2}$   | 4.90         | 5                | 6                                         |
| 4.04         | 4                | 5.70         | $5\frac{3}{4}$   | 7                                         |
| 4.62         | $4\frac{5}{8}$   | 6.50         | $6\frac{1}{2}$   | 8                                         |
| 5.20         | $5\frac{1}{4}$   | 7.35         | $7\frac{1}{2}$   | 9                                         |

**Impact Screens** are said to be preferable to trommels for handling minus  $\frac{1}{2}$ -in. material, for the following reasons: (1) Higher separation efficiency; (2) lower first cost for equipment and erection; (3) repairs can be made more speedily; (4) greater accessibility to all parts. A statement of approximate capacity for various meshes is given in Table XVIII.

The **Sturtevant-Newaygo Separator** (Fig. 57) operates on the principle of light hammer taps on reinforced screen surface. It has an output grade range from  $\frac{1}{4}$  in. to 180 mesh; and from one to four products can be made with one machine. The capacity of such machines is given in Table XIX.

TABLE XVII.—MINIMUM SIZE HOLES, SQUARE OR ROUND, WHICH MAY BE PUNCHED IN STEEL PLATES<sup>11</sup>

| Thickness of plates |        | Smallest hole  |                     |
|---------------------|--------|----------------|---------------------|
| Birmingham gauge    | Inches | Millimeters    | Fraction of an inch |
| 26                  | 0.018  | $\frac{3}{4}$  | ....                |
| 24                  | 0.022  | 1              | ....                |
| 22                  | 0.028  | ....           | $\frac{3}{64}$      |
| 20                  | 0.035  | $1\frac{1}{4}$ | ....                |
| 18                  | 0.049  | $1\frac{1}{2}$ | $\frac{1}{16}$      |
| 16                  | 0.065  | 2              | $\frac{5}{64}$      |
| 14                  | 0.083  | 3              | $\frac{1}{8}$       |
| 12                  | 0.109  | $3\frac{1}{2}$ | $\frac{9}{64}$      |
| 10                  | 0.134  | $4\frac{1}{2}$ | $\frac{3}{16}$      |
| 8                   | 0.165  | $6\frac{1}{2}$ | $\frac{1}{4}$       |
| $\frac{3}{16}$      | 0.187  | 7              | $\frac{9}{32}$      |
| $\frac{1}{4}$       | 0.25   | 10             | $\frac{1}{16}$      |
| $\frac{5}{16}$      | 0.312  | ....           | 1                   |

TABLE XVIII.—CAPACITY OF IMPACT SCREENS<sup>31</sup>

| Size of screen: 4 ft. × 3 ft. |                 |
|-------------------------------|-----------------|
| Mesh                          | Tons per 24 hr. |
| 4                             | 200-250         |
| 10                            | 150-175         |
| 16                            | 100-125         |
| 20                            | 75- 90          |
| 30                            | 50- 60          |
| 40                            | 40- 50          |
| 60                            | 30- 40          |
| 80                            | 20- 30          |
| 100                           | 15- 20          |

The **Bunker Hill Screen** (Fig. 58) is in the form of a cone connected at its base with a hollow shaft placed at an angle of  $45^{\circ}$ . The screen is driven by gearing, and may be operated at from 20 r.p.m. The feed strikes the screen tangentially, the fines are delivered through the wire cloth, and the oversize

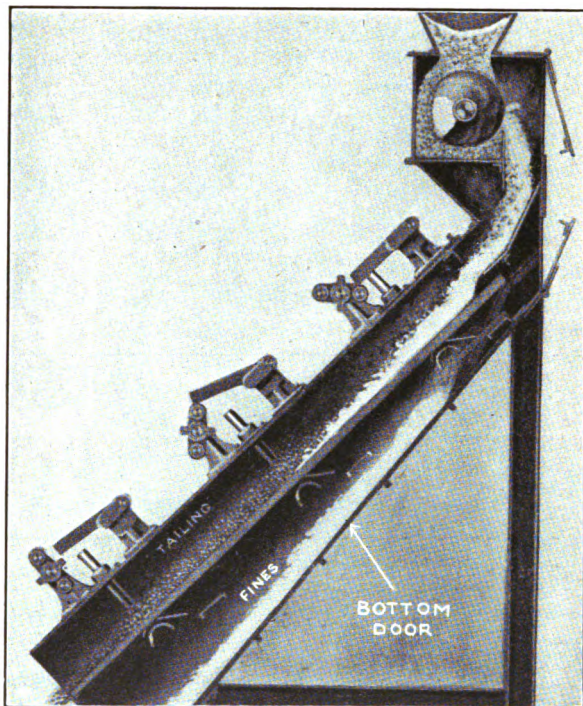


FIG. 57.—Sturtevant-Newaygo separator.<sup>32</sup>

passes through the hollow shaft. A spray of water through the screen from the outside materially assists separation.

The **Callow Screen** (Fig. 59) consists of an endless-belt screen revolving on rollers. The pulp is delivered onto the upper surface of the screen, through which the fines pass. Water sprays are used to clean the screen and assist in the removal of

oversize. Approximate capacities of the 24-in. belt machine are given as follows:

|                           |                        |
|---------------------------|------------------------|
| Using 16-mesh screen..... | 300 tons per 24 hours  |
| Using 60-mesh screen..... | 150 tons per 24 hours  |
| Using 80-mesh screen..... | 100 tons per 24 hours. |

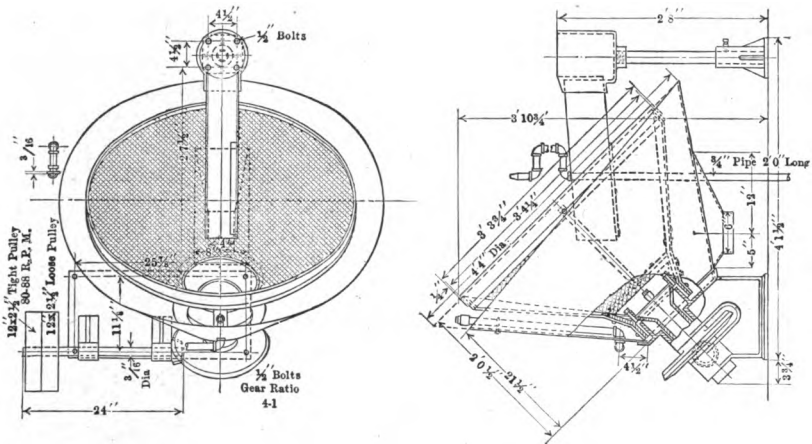


FIG. 58.—Bunker Hill screen.<sup>13</sup>

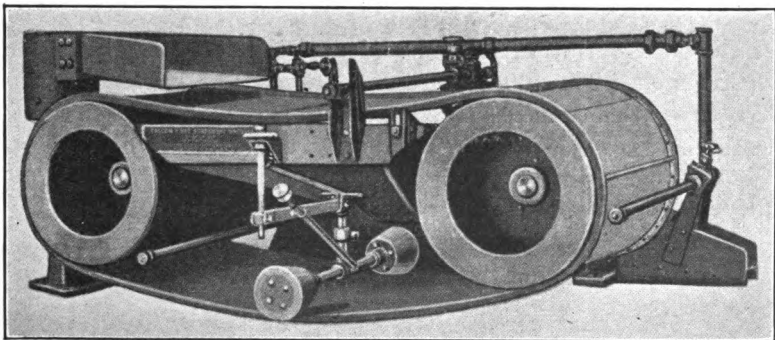


FIG. 59.—Callow traveling-belt screen.<sup>12</sup>

TABLE XIX.—NEWAYGO VIBRATORY-SCREEN OPERATION<sup>32</sup>

| Kind of wire | Cloth mesh | Diameter of wire | Opening | Output approx. mesh | Capacity approx. lb. per hour No. 1 separator | Capacity approx. lb. per hour No. 3 separator |
|--------------|------------|------------------|---------|---------------------|-----------------------------------------------|-----------------------------------------------|
| Steel.....   | 2          | 0.120            | 0.380   | 4                   | 14,000                                        | 28,000                                        |
|              | 4          | 0.080            | 0.170   | 8                   | 12,000                                        | 24,000                                        |
|              | 6          | 0.047            | 0.120   | 12                  | 10,500                                        | 21,000                                        |
|              | 8          | 0.047            | 0.078   | 16                  | 9,000                                         | 18,000                                        |
|              | 12         | 0.032            | 0.051   | 24                  | 8,500                                         | 17,000                                        |
|              | 16         | 0.023            | 0.0395  | 30                  | 7,500                                         | 15,000                                        |
|              | 20         | 0.018            | 0.032   | 40                  | 6,500                                         | 13,000                                        |
|              | 24         | 0.015            | 0.0267  | 50                  | 5,500                                         | 11,000                                        |
|              | 30         | 0.0135           | 0.0198  | 60                  | 4,000                                         | 8,000                                         |
| Brass.....   | 40         | 0.011            | 0.0140  | 80                  | 2,500                                         | 5,000                                         |
|              | 30         | 0.012            | 0.0213  | 60                  | 4,000                                         | 8,000                                         |
|              | 40         | 0.010            | 0.015   | 80                  | 2,500                                         | 5,000                                         |
|              | 60         | 0.008            | 0.0087  | 100                 | 1,000                                         | 2,000                                         |
|              | 80         | 0.00575          | 0.0068  | 140                 | 700                                           | 1,400                                         |
|              | 100        | 0.0045           | 0.0055  | 180                 | 550                                           | 1,100                                         |

**The Number of Holes per Linear Inch** in a screen is termed the *mesh*. This figure has no significance unless the wire sizes are also given. The general adoption of a standard series of screens with fixed ratio differences in the mesh apertures is urgently needed.

The word **Screening** is used to denote the number of holes per square inch. Thus 40 by 40 mesh is known as 1600 screening. The use of this term to designate screen sizes is to be deprecated, as it conveys no definite information as to the actual dimensions of the screening apertures.

**Screen or Mesh Aperture** is a term usually referring to the linear dimension of opening from wire to wire. One dimension only is given when the opening is square and two dimensions are given when the opening is oblong.

**Needle-Slot Punched Screens** are sometimes used for battery and other mill work. The slots are usually about  $\frac{1}{2}$  in. in length. Trade sizes of such screening are given in Table XX.



TABLE XX.—NEEDLE-SLOT SCREENS<sup>11</sup>

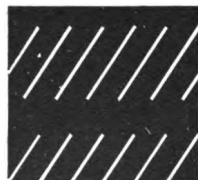
| No. | Mesh | Width of slot | U. S. Standard gauge steel | Decimal of an inch | Weight per sq. ft. lb. + |
|-----|------|---------------|----------------------------|--------------------|--------------------------|
| 000 | 6    | 0.094         | 16                         | 0.0625             | 2.55                     |
| 00  | 8    | 0.083         | 16                         | 0.0625             | 2.55                     |
| 0   | 10   | 0.070         | 16                         | 0.0625             | 2.55                     |
| 1   | 12   | 0.058         | 16                         | 0.0625             | 2.55                     |
| 2   | 14   | 0.049         | 16                         | 0.0625             | 2.55                     |
| 3   | 16   | 0.042         | 18                         | 0.05               | 2.04                     |
| 4   | 18   | 0.035         | 18                         | 0.05               | 2.04                     |
| 5   | 20   | 0.029         | 20                         | 0.0375             | 1.53                     |
| 6   | 25   | 0.027         | 20                         | 0.0375             | 1.53                     |
| 7   | 30   | 0.024         | 20                         | 0.0375             | 1.53                     |
| 8   | 35   | 0.022         | 20                         | 0.0375             | 1.53                     |
| 9   | 40   | 0.020         | 22                         | 0.0312             | 1.275                    |
| 10  | 50   | 0.018         | 23                         | 0.028              | 1.147                    |
| 11  | 55   | 0.0165        | 23                         | 0.028              | 1.147                    |
| 12  | 60   | 0.015         | 24                         | 0.025              | 1.02                     |
| 13  | 70   | 0.0135        | 24                         | 0.025              | 1.02                     |
| 14  | 80   | 0.012         | 26                         | 0.0187             | 0.765                    |



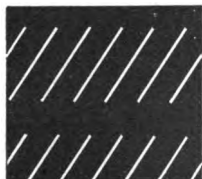
No. 1-(12 Mesh)



No. 3-(16 Mesh)



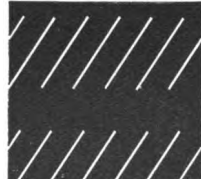
No. 5-(20 Mesh)



No. 7-(30 Mesh)



No. 10-(50 Mesh)



No. 12-(60 Mesh)

FIG. 60.—Standard diagonal needle-slot screens.<sup>11</sup>

Actual-size diagrams are reproduced in Fig. 60. With this type of screen the total discharge area is small when comparison is made with a wire-mesh, oblong-opening screen of the same aperture width.

**Rittinger's Screen Series** (Table XXI) is of limited application, the fundamental screen opening being 1 mm. and the ratio between successive openings  $\sqrt{2}$ .

The **Screen Series** suggested by **Richards**, in which the ratio between successive openings is  $\sqrt[4]{2}$ , disposes of certain disadvantages of the Rittinger series, but results in an unnecessary multiplication of screens in the coarser sizes. Values of the finer sizes are given in Table XXII.

TABLE XXI.—RITTINGER'S SIEVE SCALE<sup>a</sup>

| 1.414 = ( $\sqrt{2}$ ) is taken as ratio of diameter of hole in screen to the one above it |                                       |                                            |
|--------------------------------------------------------------------------------------------|---------------------------------------|--------------------------------------------|
| Diameters, mm.                                                                             | Areas if holes are square,<br>sq. mm. | Volumes if particles are<br>cubes, cu. mm. |
| 64.0                                                                                       | 4,096.0                               | 262,144.0                                  |
| 45.2                                                                                       | 2,048.0                               | 92,668.0                                   |
| 32.0                                                                                       | 1,024.0                               | 32,768.0                                   |
| 22.6                                                                                       | 512.0                                 | 11,583.0                                   |
| 16.0                                                                                       | 256.0                                 | 4,096.0                                    |
| 11.3                                                                                       | 128.0                                 | 1,448.0                                    |
| 8.0                                                                                        | 64.0                                  | 512.0                                      |
| 5.7                                                                                        | 32.0                                  | 181.0                                      |
| 4.0                                                                                        | 16.0                                  | 64.0                                       |
| 2.8                                                                                        | 8.0                                   | 22.6                                       |
| 2.0                                                                                        | 4.0                                   | 8.0                                        |
| 1.4                                                                                        | 2.0                                   | 2.8                                        |
| 1.0                                                                                        | 1.0                                   | 1.0                                        |
| 0.71                                                                                       | 0.5                                   | 0.35                                       |
| 0.50                                                                                       | 0.25                                  | 0.125                                      |
| 0.35                                                                                       | 0.125                                 | 0.044                                      |
| 0.25                                                                                       | 0.063                                 | 0.016                                      |

TABLE XXII.—THE RICHARDS OR DOUBLE RITTINGER RATIO OF SCREEN OPENINGS IN SMALL SIZES<sup>33</sup>

| Opening (ratio $\sqrt[4]{2} = 1.189$ ) |             | Mesh | Diameter of wire, in. |
|----------------------------------------|-------------|------|-----------------------|
| Inches                                 | Millimeters |      |                       |
| 0.0082                                 | 0.208       | 65   | 0.0072                |
| 0.0069                                 | 0.175       | 80   | 0.0056                |
| 0.0058                                 | 0.147       | 100  | 0.0042                |
| 0.0049                                 | 0.124       | 115  | 0.0038                |
| 0.0041                                 | 0.104       | 150  | 0.0026                |
| 0.0035                                 | 0.088       | 170  | 0.0024                |
| 0.0029                                 | 0.074       | 200  | 0.0021                |

TABLE XXIII.—THE TYLER STANDARD SCREEN SCALE<sup>34</sup>

| Opening (ratio $\sqrt{2} = 1.414$ ) |             | Mesh | Diameter of wire, in. |
|-------------------------------------|-------------|------|-----------------------|
| Inches                              | Millimeters |      |                       |
| 1.050                               | 26.67       | ...  | 0.149                 |
| 0.742                               | 18.85       | ...  | 0.135                 |
| 0.525                               | 13.33       | ...  | 0.105                 |
| 0.371                               | 9.423       | ...  | 0.092                 |
| 0.263                               | 6.680       | 3    | 0.070                 |
| 0.185                               | 4.699       | 4    | 0.065                 |
| 0.131                               | 3.327       | 6    | 0.036                 |
| 0.093                               | 2.362       | 8    | 0.032                 |
| 0.065                               | 1.651       | 10   | 0.035                 |
| 0.046                               | 1.168       | 14   | 0.025                 |
| 0.0328                              | 0.833       | 20   | 0.0172                |
| 0.0232                              | 0.589       | 28   | 0.0125                |
| 0.0164                              | 0.417       | 35   | 0.0122                |
| 0.0116                              | 0.295       | 48   | 0.0092                |
| 0.0082                              | 0.208       | 65   | 0.0072                |
| 0.0058                              | 0.147       | 100  | 0.0042                |
| 0.0041                              | 0.104       | 150  | 0.0026                |
| 0.0029                              | 0.074       | 200  | 0.0021                |

The **Tyler Ratio of Screen Openings** uses the Rittinger series from 0.0029-in. opening to 1.05 in. in 18 sieves. Alternate units in the Richards ratio are used for the smaller sizes. Details are given in Table XXIII.

The **Screen Standards Suggested by Stadler** as representing a mathematically correct scale reduction ratio of 1:4 from one inch downward are given in Table XXIV. These are based on a system assuming a regular reduction of the particle to half its volume at each step, giving a ratio of  $\frac{1}{\sqrt[3]{2}}$ ; or, by omitting alternate grades, of  $\frac{1}{\sqrt[3]{4}}$ .

TABLE XXIV.—STADLER'S SCREEN SCALE<sup>35</sup>

| Mathematically correct scale;<br>reduction ratio 1:4 |             |        | Nearest I. M. M. standard laboratory screens |             |
|------------------------------------------------------|-------------|--------|----------------------------------------------|-------------|
| Mesh aperture                                        |             | Number | Mesh aperture                                |             |
| Inches                                               | Millimeters |        | Inches                                       | Millimeters |
| 1.0                                                  | 25.4        |        |                                              |             |
| 0.630                                                | 16.0        |        |                                              |             |
| 0.3969                                               | 10.080      |        |                                              |             |
| 0.250                                                | 6.35        |        |                                              |             |
| 0.1575                                               | 4.0033      |        |                                              |             |
| 0.09922                                              | 2.52        | 5      | 0.10                                         | 2.540       |
| 0.06250                                              | 1.5874      | 8      | 0.062                                        | 1.574       |
| 0.03937                                              | 1.0         | 12     | 0.0416                                       | 1.056       |
| 0.0248                                               | 0.630       | 20     | 0.025                                        | 0.635       |
| 0.01562                                              | 0.3968      | 30     | 0.0166                                       | 0.421       |
| 0.00984                                              | 0.250       | 50     | 0.01                                         | 0.254       |
| 0.00620                                              | 0.1575      | 80     | 0.0062                                       | 0.157       |
| 0.00391                                              | 0.0992      | 120    | 0.0042                                       | 0.107       |
| 0.00246                                              | 0.0625      | 200    | 0.0025                                       | 0.063       |

The **U. S. Bureau of Standards Screen Scale** is given in Table XXV and commences with a 200-mesh screen with a square opening of 0.0029 in. and a wire of 0.0021 in. diameter. The ratio increases 1.414 between successive sizes.

TABLE XXV.—U. S. BUREAU OF STANDARDS SCREEN SCALE

| Mesh per linear inch | Opening, in. | Opening, mm. | Diameter of wire, in. | Diameter of wire, mm. | Area of openings, sq. in. |
|----------------------|--------------|--------------|-----------------------|-----------------------|---------------------------|
| ...                  | 4.20         | 106.60       | 0.375                 | 9.52                  | 17.64                     |
| ...                  | 2.97         | 75.39        | 0.207                 | 5.26                  | 8.82                      |
| ...                  | 2.10         | 53.33        | 0.192                 | 4.88                  | 4.41                      |
| ...                  | 1.49         | 37.73        | 0.149                 | 3.78                  | 2.20                      |
| ...                  | 1.05         | 26.67        | 0.149                 | 3.78                  | 1.10                      |
| ...                  | 0.742        | 18.85        | 0.135                 | 3.43                  | 0.551                     |
| ...                  | 0.525        | 13.33        | 0.105                 | 2.67                  | 0.276                     |
| ...                  | 0.371        | 9.423        | 0.092                 | 2.34                  | 0.138                     |
| 3                    | 0.263        | 6.680        | 0.070                 | 1.78                  | 0.069                     |
| 4                    | 0.185        | 4.699        | 0.065                 | 1.65                  | 0.034                     |
| 6                    | 0.131        | 3.327        | 0.036                 | 0.91                  | 0.017                     |
| 8                    | 0.093        | 2.362        | 0.032                 | 0.81                  | 0.0086                    |
| 10                   | 0.065        | 1.651        | 0.035                 | 0.89                  | 0.0042                    |
| 14                   | 0.046        | 1.168        | 0.025                 | 0.64                  | 0.0021                    |
| 20                   | 0.0328       | 0.833        | 0.0172                | 0.44                  | 0.00108                   |
| 28                   | 0.0232       | 0.589        | 0.0125                | 0.32                  | 0.00054                   |
| 35                   | 0.0164       | 0.417        | 0.0122                | 0.31                  | 0.00027                   |
| 48                   | 0.0116       | 0.295        | 0.0092                | 0.23                  | 0.000135                  |
| 65                   | 0.0082       | 0.208        | 0.0072                | 0.18                  | 0.0000672                 |
| 100                  | 0.0058       | 0.147        | 0.0042                | 0.11                  | 0.0000336                 |
| 150                  | 0.0041       | 0.104        | 0.0026                | 0.07                  | 0.0000168                 |
| 200                  | 0.0029       | 0.074        | 0.0021                | 0.05                  | 0.0000084                 |

If the analysis is to be carried finer than 0.0029 in. (200 mesh), the next finer sieve opening in the screen scale series is 0.002 in. (280 mesh).

The Screen Standards Adopted by the Institution of Mining and Metallurgy (Table XXVI) are designed so that the diameter of the wire used approximates, as closely as possible, to the width of aperture. The cost of manufacturing the finer mesh screens is considerable, and the system presents no obvious advantages. It lacks a fixed ratio between successive sieve openings.

**Screening Analyses** are usually made on unit quantities of material, viz.: 100, 200, 500, or 1000 gm., in order to facilitate percentage calculation. The amount to be taken will depend

TABLE XXVI.—I. M. M. STANDARD LABORATORY SCREENS

| Number of openings<br>per linear inch | Diameter of wire |       | Aperture |       | Screening area,<br>per cent. |
|---------------------------------------|------------------|-------|----------|-------|------------------------------|
|                                       | In.              | Mm.   | In.      | Mm.   |                              |
| 5                                     | 0.1              | 2.540 | 0.1      | 2.540 | 25.00                        |
| 8                                     | 0.063            | 1.600 | 0.062    | 1.574 | 24.60                        |
| 10                                    | 0.05             | 1.270 | 0.05     | 1.270 | 25.00                        |
| 12                                    | 0.0417           | 1.059 | 0.0416   | 1.056 | 24.92                        |
| 16                                    | 0.0313           | 0.795 | 0.0312   | 0.792 | 24.92                        |
| 20                                    | 0.025            | 0.635 | 0.025    | 0.635 | 25.00                        |
| 30                                    | 0.0167           | 0.424 | 0.0166   | 0.421 | 24.80                        |
| 40                                    | 0.0125           | 0.317 | 0.0125   | 0.317 | 25.00                        |
| 50                                    | 0.01             | 0.254 | 0.01     | 0.254 | 25.00                        |
| 60                                    | 0.0083           | 0.211 | 0.0083   | 0.211 | 24.80                        |
| 70                                    | 0.0071           | 0.180 | 0.0071   | 0.180 | 24.70                        |
| 80                                    | 0.0063           | 0.160 | 0.0062   | 0.157 | 24.60                        |
| 90                                    | 0.0055           | 0.139 | 0.0055   | 0.139 | 24.50                        |
| 100                                   | 0.005            | 0.127 | 0.005    | 0.127 | 25.00                        |
| 120                                   | 0.0041           | 0.104 | 0.0042   | 0.107 | 25.40                        |
| 150                                   | 0.0033           | 0.084 | 0.0033   | 0.084 | 24.50                        |
| 200                                   | 0.0025           | 0.063 | 0.0025   | 0.063 | 25.00                        |

on the weights obtained in the different sizings, and it is generally advisable to make a rough preliminary sizing on 100 gm. to see whether the amounts obtained in all sizes are likely to be sufficient to insure accuracy in weighing. Assay requirements will also influence the amount taken when it is necessary to determine subsequently the metallic contents of the various gradings.

The material is usually thoroughly **Dried and Mixed** before the final sample is taken for sieving. In the case where the pulp carries a percentage of comparatively coarse (*e.g.*,  $\frac{1}{4}$  in.) gravel, it is often impracticable to select a final sample for sieving carrying a true percentage of the coarser material. In the latter case it will often be found advisable to mix and weigh the ore while still damp so that no segregation of coarse particles takes place. The sample taken is then dried with care and any loss avoided. The dry weight is recorded and the entire sample screened. The

percentage through each sieve is then calculated from the weights obtained.

**The Mixed Method for Grading Analysis** is recommended by Stadler and may be described as follows: A convenient weight of the dried sample is transferred to a suitable metal frame having the finest screen it is proposed to use fitted into the bottom. The finest material is then removed by wet screening and the remaining washed product is dried in the same screen frame, and the grading continued and finished on the re-dried sand. The percentage of fines removed by wet screening is estimated by difference.

**Advantages Claimed for the Mixed Method** are as follows:

- (a) Greater accuracy.
- (b) Saving in time in spite of the double drying, as with washed sands in a comparatively short time a clearly defined end of the operation of screening is reached.
- (c) No dusting.

**Drying of Samples** should be carried out in the final stages on steam or water baths. Stadler has pointed out that the use of a high temperature may result in splitting of the grains and consequent error in grading analysis result.

**The Selection of a Series of Screening Sieves** should be influenced by the fact that all subsequent calculations and graphic presentations of results are simplified when a scale has been adopted in which there is a constant ratio between the openings. In this respect the Tyler series (Table XXIII) is recommended.

**Screening Tests** are made by placing the weighed portion of the dry ground ore on the mesh of the largest of a series of screens arranged in order, and commencing with an aperture through which the whole of the sample just passes. The nest of screens is then subjected to a rotary shaking motion either by hand or machine. The separation is facilitated by the use, in each screen, of an iron washer, which tends to break up any small balls of slime and to give the screen a certain amount of vibration. Before removing any screen from the one next below it, it is advis-

Cumulative Direct Diagram of Screen Analysis on Sample of Roll crushing  
 Name Midas Gold Mfg. Co., Red Butte, Idaho Date November 25, 1912

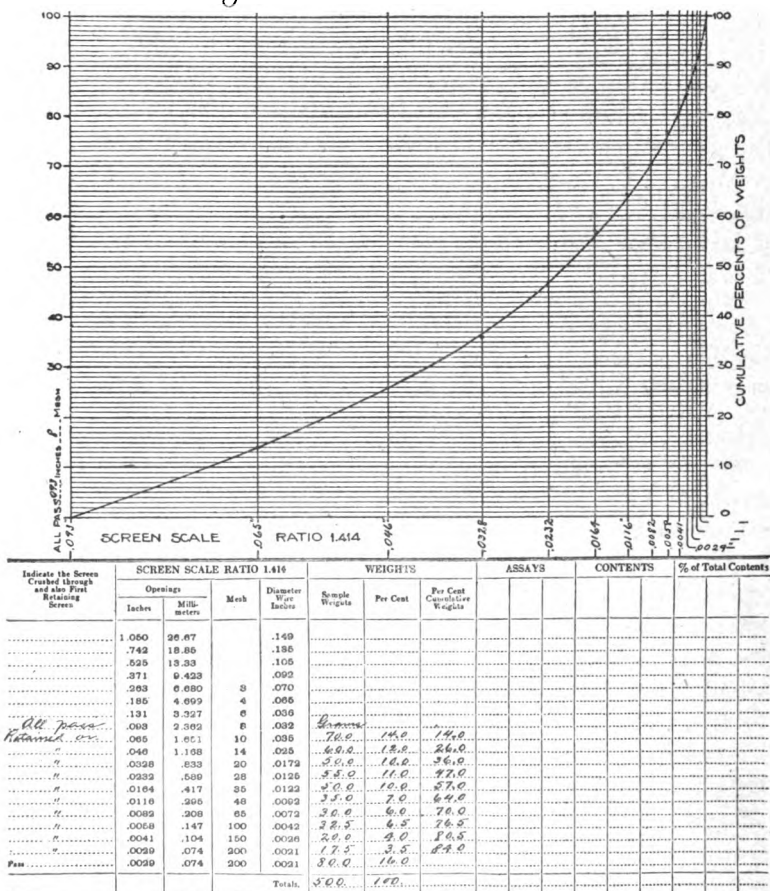
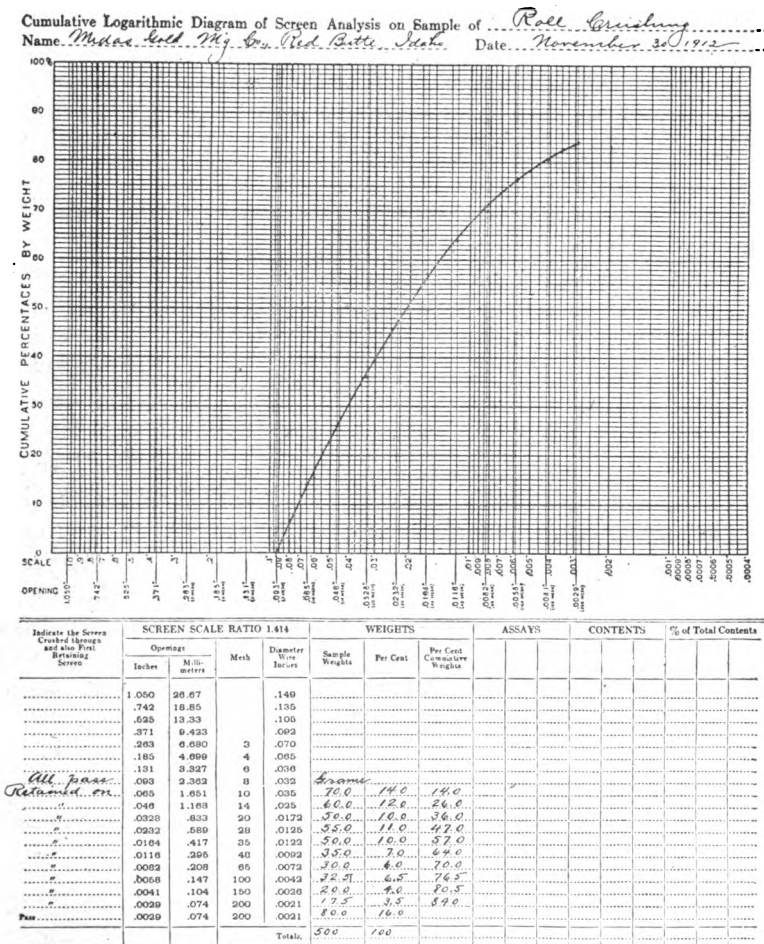


FIG. 61.—Graphic statement of screen analysis.<sup>34</sup>





able to test the oversize with the tips of the fingers to see whether the separation has been efficient.

**An Inevitable Loss** occurs in sieving operations. Where particular care is taken to clean the screens after each test it may be assumed that the loss is in the finest material. The actual weighed proportion of the latter may then be credited with an additional amount (usually varying from one-tenth to one-fifth of 1 per cent. of the original weight of ore), so that the total weight of sieved materials should equal the weight originally taken.

**Wet Screening** is seldom practised, although it is a useful method where it is found necessary to determine the approximate percentage of fine colloid material (such as clay), as distinct from ground ore, passing the finest screen. The adoption of wet screening results in a greater proportion of fines being accounted for than in dry screening, and it is therefore advisable in reporting screen analyses by wet method to state the fact.

**The Results of Grading Analyses with Fixed-Ratio Sieves may be Plotted** in the manner shown in Figs. 61 and 62. The former is an example of a cumulative direct diagram of the analysis. The vertical lines represent the screen openings. The curve starts at the lower left-hand corner and rises toward the top right-hand corner according to the cumulative percentages of screened products recorded in the analysis. In Fig. 62 the same results are plotted as a cumulative logarithmic diagram in which equal distances on the horizontal scale represent equal ratios, and where the logarithms of the diameters of the openings are used to plot the curve in conjunction with the determined percentages.

## SECTION VII

### COARSE TO MEDIUM CRUSHING IN JAW, GYRATORY, DISC, OR OTHER MACHINES

In the **Blake-Type Crusher** the movable jaw is supported at the top. This is the usual type of crusher adopted in average-size or small mills. Figure 63 illustrates the design and Table XXVII

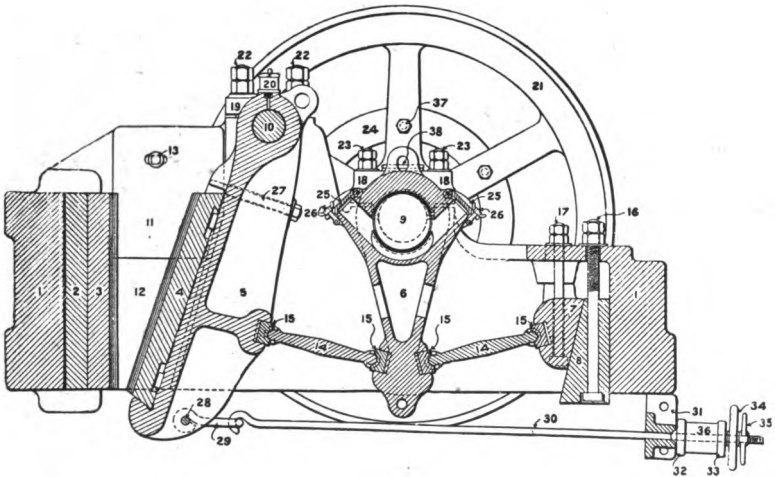


FIG. 63.—Farrel crusher.<sup>36</sup>

- |                             |                                     |                                       |
|-----------------------------|-------------------------------------|---------------------------------------|
| 1. Main frame.              | 15. Toggle bearing.                 | 27. Bolt for swing-jaw plate          |
| 2. Round back.              | 16. Bolt for wedge.                 | 28. Shackle pin.                      |
| 3. Fixed jaw plate          | 17. Bolt for toggle block.          | 29. Spring-rod shackle.               |
| 4. Swing jaw plate          | 18. Cover for main bearing.         | 30. Spring rod.                       |
| 5. Swing jaw.               | 19. Cover for swing jaw shaft.      | 31. Spring bar.                       |
| 6. Pitman.                  | 20. Grease cup.                     | 32. Washer.                           |
| 7. Toggle block.            | 21. Balance wheel.                  | 33. Washer.                           |
| 8. Wedge.                   | 22. Bolt for swing-jaw shaft cover. | 34. Hand wheel.                       |
| 9. Eccentric shaft.         | 23. Bolt for main bearing.          | 35. Thumb nut.                        |
| 10. Swing-jaw shaft.        | 24. Pulley.                         | 36. Rubber spring.                    |
| 11. Upper half cheek plate. | 25. Grease-box cover.               | 37. Bolt for pulley.                  |
| 12. Lower half cheek plate. | 26. Bolt and thumb screw.           | 38. Grease-box cover on main bearing. |
| 13. Bolt for cheek plate.   |                                     |                                       |
| 14. Toggle.                 |                                     |                                       |

gives details of operation. Details of a class with unusual feed opening dimensions, designed for fine crushing, are given in Table XXVIII.

The typical **Blake Crusher Diagram**, illustrating the tendency toward invariable composition of product, irrespective of class

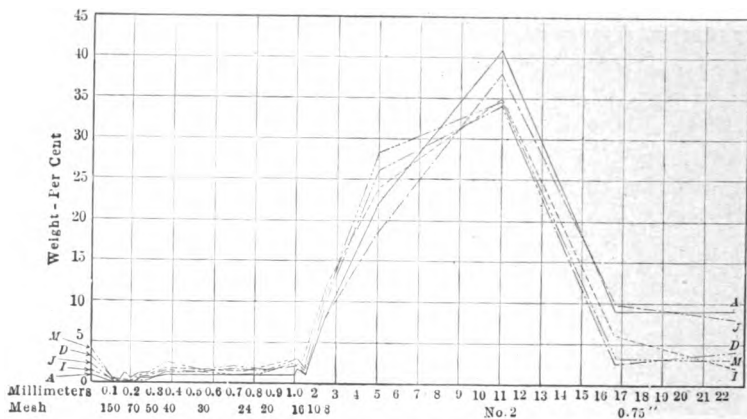


FIG. 64.—Curve showing uniformity of grade produced in crushing different materials in a Blake crusher.<sup>38</sup>

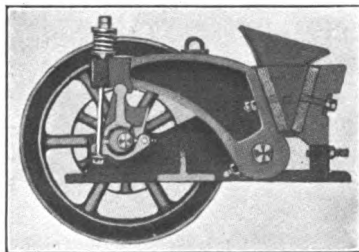


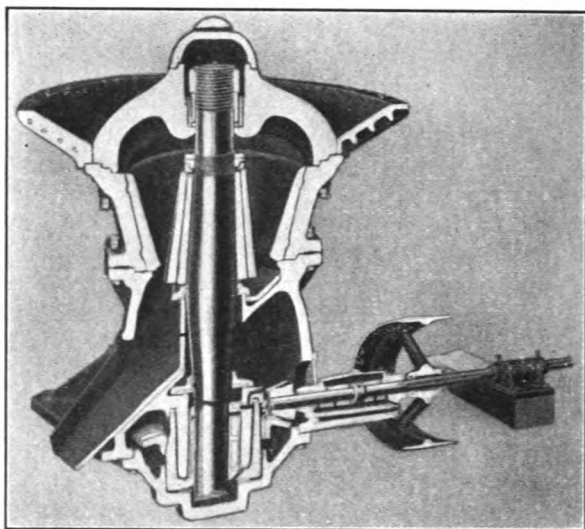
FIG. 65.—Dodge crusher.<sup>39</sup>

of material fed, is shown in Fig. 64. The individual curves refer to different tests with different materials. The crusher jaws were set to 1 inch.

The **Dodge-Type Crusher** (Fig. 65) has its movable jaw pivoted at the lower end and consequently produces a finer and more even product than the Blake. It is not made in large sizes.

TABLE XXVII.—BLAKE CRUSHER DATA.<sup>37</sup>

| Size receiving capacity in inches | Approximate capacity, in tons, per day of 10 hr. to either one of sizes stated |       |           |             |           |             | Size of pulley, in. | Speed in. | Horse-power, | Approximate total weight, lb. |      |     |
|-----------------------------------|--------------------------------------------------------------------------------|-------|-----------|-------------|-----------|-------------|---------------------|-----------|--------------|-------------------------------|------|-----|
|                                   | Tons                                                                           |       | In.       |             | Tons      |             |                     |           |              |                               | In.  |     |
|                                   | Tons                                                                           | In.   | Tons      | In.         | Tons      | In.         |                     |           |              |                               | Tons | In. |
| 2 × 4                             | .....                                                                          | ..... | .....     | .....       | .....     | .....       | .....               | .....     | .....        | 163                           |      |     |
| 8 × 14                            | 100 to 2½                                                                      | ..... | 85 to 2   | 60 to 1½    | 35 to 1   | 24 × 10 (1) | 275-300             | 8-12      | 6,400        |                               |      |     |
| 10 × 16                           | 170 to 3                                                                       | ..... | 150 to 2½ | 125 to 2    | 100 to 1½ | 30 × 12 (1) | 275-300             | 12-18     | 9,100        |                               |      |     |
| 12 × 20                           | 230 to 3                                                                       | ..... | 200 to 2½ | 175 to 2    | 130 to 1½ | 36 × 12 (1) | 250-275             | 18-25     | 15,000       |                               |      |     |
| 13 × 24                           | 300 to 3                                                                       | ..... | 260 to 2½ | 215 to 2    | 160 to 1½ | 42 × 8 (2)  | 250-275             | 20-30     | 22,900       |                               |      |     |
| 15 × 24                           | 400 to 4                                                                       | ..... | 350 to 3½ | 300 to 3    | .....     | 42 × 8 (2)  | 250-275             | 20-30     | 22,900       |                               |      |     |
| 13 × 30                           | 375 to 3                                                                       | ..... | 320 to 2½ | 275 to 2    | 200 to 1½ | 42 × 10 (2) | 250-275             | 30-40     | 30,000       |                               |      |     |
| 15 × 30                           | 500 to 5                                                                       | ..... | 450 to 4  | 375 to 3    | .....     | 42 × 10 (2) | 250-275             | 30-40     | 30,000       |                               |      |     |
| 18 × 36                           | 650 to 4                                                                       | ..... | 575 to 3½ | 500 to 3    | 450 to 2½ | 42 × 14 (2) | 250-275             | 50-60     | 57,000       |                               |      |     |
| 24 × 36                           | 1,000 to 6                                                                     | ..... | 850 to 5  | 750 to 4½   | 700 to 4  | 48 × 14 (2) | 250-275             | 50-60     | 57,000       |                               |      |     |
| 24 × 48                           | 1,200 to 6                                                                     | ..... | .....     | 800 to 4    | .....     | 72 × 12 (2) | 200-225             | .....     | 98,000       |                               |      |     |
| 30 × 60                           | 1,500 to 6                                                                     | ..... | .....     | 1,200 to 4½ | .....     | 90 × 18 (2) | 180-210             | .....     | 120,000      |                               |      |     |

FIG. 66.—Sectional view gyratory breaker.<sup>18</sup>TABLE XXVIII.—APPROXIMATE CAPACITIES OF FARREL FINE CRUSHERS<sup>16</sup>

| Size of receiving capacity |         | Approximate capacity in tons, per day of 10 hr., to any one of the sizes stated |         |         |      | Size of pulley | Revs. of pulley | Total weight | Weight of heaviest piece |
|----------------------------|---------|---------------------------------------------------------------------------------|---------|---------|------|----------------|-----------------|--------------|--------------------------|
| In.                        | Tons    | In.                                                                             | Tons    | In.     | Tons | In.            |                 | Lb.          | Lb.                      |
| 20 × 4                     | 30 to 1 | 15 to ½                                                                         | 7 to ¼  | 48 × 6½ | 300  | 7,000          | 3,500           |              |                          |
| 30 × 4                     | 50 to 1 | 25 to ½                                                                         | 12 to ¼ | 48 × 11 | 300  | 10,500         | 5,500           |              |                          |

TABLE XXIX.—APPROXIMATE CAPACITY OF DODGE CRUSHERS<sup>11</sup>

| Size of jaw opening, in. | Horsepower required | No. of tons per hour, nut size | Revolutions per minute |
|--------------------------|---------------------|--------------------------------|------------------------|
| 4 × 6                    | 3                   | ½                              | 300                    |
| 7 × 9                    | 6                   | 1½ to 2½                       | 300                    |
| 7 × 9 Sectional          | 6                   | 1½ to 2½                       | 300                    |
| 8 × 12                   | 10                  | 3 to 5                         | 300                    |
| 11 × 15                  | 15                  | 6 to 8                         | 250                    |

TABLE XXX.—GYRATORY BREAKER DATA<sup>10</sup>

| Size of crusher, No. | Size of each feed opening, in. | Finest setting                |                           | Coarsest setting             |                           | Size of driving pulley, in. | Revolutions per minute | Horse power required | Approx. weight of crusher, lb. |
|----------------------|--------------------------------|-------------------------------|---------------------------|------------------------------|---------------------------|-----------------------------|------------------------|----------------------|--------------------------------|
|                      |                                | Smallest size of product, in. | Capacity in tons per hour | Largest size of product, in. | Capacity in tons per hour |                             |                        |                      |                                |
| 1                    | 5 × 20                         | 7/8                           | 4 1/2                     | 1 7/8                        | 8 1/2                     | 24 × 6                      | 475                    | 4-6                  | 6,800                          |
| 2                    | 6 × 25                         | 1                             | 6 1/2                     | 2 1/4                        | 12 1/2                    | 24 × 8                      | 450                    | 6-10                 | 10,000                         |
| 3                    | 7 × 28                         | 1 1/4                         | 11                        | 2 3/4                        | 25                        | 28 × 10                     | 425                    | 10-15                | 16,000                         |
| 4                    | 8 × 34                         | 1 1/2                         | 20                        | 3 1/2                        | 48                        | 32 × 12                     | 400                    | 12-20                | 23,000                         |
| 5                    | 10 × 40                        | 1 3/4                         | 30                        | 4 1/4                        | 75                        | 36 × 14                     | 375                    | 20-25                | 33,000                         |
| 6                    | 12 × 44                        | 2                             | 50                        | 4 1/2                        | 120                       | 40 × 16                     | 350                    | 25-40                | 45,500                         |
| 7 1/2                | 15 × 55                        | 2 1/2                         | 80                        | 5                            | 180                       | 44 × 18                     | 350                    | 45-70                | 69,500                         |
| 8                    | 18 × 68                        | 2 3/4                         | 110                       | 5 1/2                        | 250                       | 48 × 20                     | 350                    | 65-100               | 100,000                        |
| 9                    | 21 × 76                        | 3                             | 160                       | 6                            | 350                       | 56 × 20                     | 325                    | 100-140              | 158,000                        |
| 10                   | 24 × 84                        | 3 1/2                         | 210                       | 6 1/2                        | 450                       | 56 × 24                     | 325                    | 115-160              | 180,000                        |
| 11                   | 27 × 92                        | 4                             | 260                       | 7                            | 550                       | 56 × 24                     | 325                    | 130-180              | 195,000                        |
| .....                | 36 × 130                       | 5                             | 600                       | 8                            | 1,100                     | 72 × 31                     | 280                    | 200-250              | 400,000                        |
| .....                | 42 × 136                       | 5 1/2                         | 700                       | 9                            | 1,300                     | 72 × 33                     | 280                    | 225-280              | 420,000                        |

Details of output and other information are given in Table XXIX.

**Gyratory Crushers**, as their name implies, operate on an eccentric revolving movement of an inverted cone spindle at an adjusted distance from a fixed head. Figure 66 illustrates the type, and Table XXX gives details of construction and operation.

The **Percentage of Various Sized Products from Rock Crushers** may be estimated by reference to Fig. 67. For example when

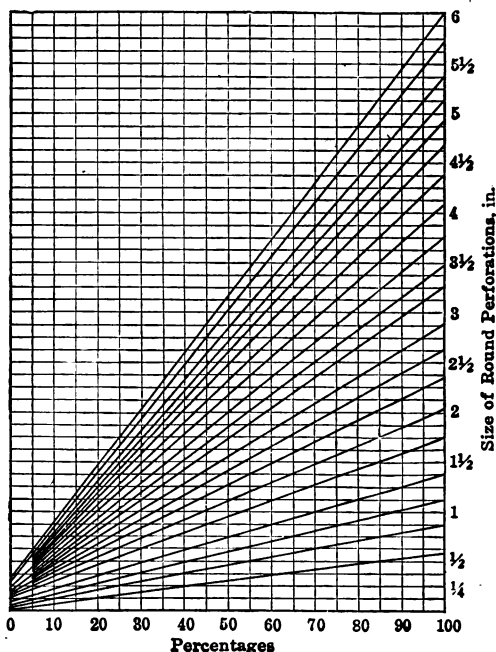


FIG. 67.—Diagram to determine size of rock-breaker product.<sup>3</sup>

crushing to pass a  $3\frac{1}{2}$ -in. ring 55 per cent. will be found to pass a 2-in. ring. Variation from these figures will occur if the rock breaks in an abnormal manner.

The **Reliance Fine Crusher** (Fig. 68) may be adjusted to produce as fine as  $\frac{1}{4}$ -in. product from a coarse feed. The motion to the movable jaw is transmitted through a toggle plate from



an eccentric and roll. Approximate capacities and other information are given in Table XXXI.

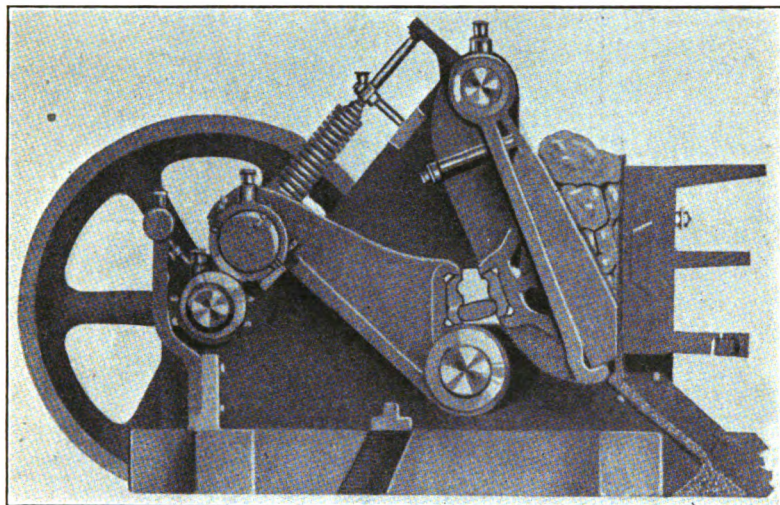


FIG. 68.—Reliance fine crusher.<sup>40</sup>

TABLE XXXI.—RELANCE FINE CRUSHER DATA<sup>40</sup>

| Size of crusher, being the size of opening or receiving capacity of jaws.....      | 8"×14" | 9"×16"    | 10"×18"    | 11"×22"    | 12"×24" |
|------------------------------------------------------------------------------------|--------|-----------|------------|------------|---------|
| <sup>1</sup> Capacity per hour in tons to $\frac{1}{2}$ " material and smaller.... | 3-4    | 4-5       | 5-6        | 7-8        | 9-11    |
| Weight, including foundation timbers, lb.....                                      | 5,200  | 7,200     | 10,000     | 15,000     | 19,500  |
| Nominal horsepower of engine and boiler required.....                              | 10-12  | 12-15     | 15-20      | 20-25      | 30-35   |
| Width of belt.....                                                                 | 8"     | 8" to 10" | 10" to 12" | 12" to 14" | 16"     |
| Diameter of belt pulley.....                                                       | 28"    | 30"       | 32"        | 36"        | 38"     |
| Nominal revolutions per minute.....                                                | 325    | 310       | 300        | 290        | 280     |

<sup>1</sup> When crushing to  $\frac{1}{4}$ " material at one operation the capacity will be reduced about 1-3 from the figures given in the table.

**Comparative Features of Gyratory and Jaw Crushers** have been discussed by H. L. Wollenberg, who has summarized his conclusions in condensed form (see Table XXXII). It is stated

TABLE XXXII.—COMPARATIVE FEATURES OF JAW AND GYRATORY CRUSHERS<sup>41</sup>

| Crushing from                                 | 7 to 1½ in. |      | 10 to 1¾ in. |       | 12 to 2½ in. |       | 18 to 3½ in. |        | 24 to 5 in. |        | 36 to 12 in. |        | 42 to 16 in. |        |
|-----------------------------------------------|-------------|------|--------------|-------|--------------|-------|--------------|--------|-------------|--------|--------------|--------|--------------|--------|
|                                               | J           | G    | J            | G     | J            | G     | J            | G      | J           | G      | J            | G      | J            | G      |
| Type of crusher                               |             |      |              |       |              |       |              |        |             |        |              |        |              |        |
| Size of feed opening, in....                  | 10×77       | 56   | 20×10        | 10×80 | 24×12        | 12×88 | 36×18        | 18×136 | 36×24       | 24×198 | 42×36        | 36×282 | 60×42        | 42×345 |
| Capacity in tons per hour                     | 4           | 7    | 12           | 30    | 25           | 70    | 60           | 130    | 85          | 400    | 160          | 900    | 300          | 1200   |
| Weight in tons.....                           | 4           | 8    | 9            | 18    | 15           | 24    | 29           | 50     | 30          | 95     | 55           | 200    | 100          | 300    |
| Hourly capacity + tons weight.....            | 1           | 0.37 | 1.25         | 1.66  | 1.67         | 2.91  | 2.07         | 2.60   | 2.83        | 4.22   | 2.90         | 4.5    | 3            | 4      |
| Installed h.p.....                            | 8           | 12   | 20           | 25    | 30           | 50    | 65           | 90     | 65          | 150    | 100          | 200    | 150          | 250    |
| Hourly capacity + installed h.p.....          | 0.5         | 0.58 | 0.60         | 1.20  | 0.83         | 1.40  | 0.92         | 1.44   | 1.31        | 2.67   | 1.60         | 4.5    | 2            | 4.8    |
| Height, ft. (disch. spout to feed floor)..... | 3           | 5½   | 3            | 7½    | 5            | 8     | 6            | 10     | 6           | 15     | 7            | 23     | 8            | 26     |
| Width, ft. (including the pulleys).....       | 6½          | 10   | 7            | 13    | 8            | 13    | 13           | 13     | 13          | 20     | 13           | 27     | 15           | 30     |
| Length, ft. (over all)....                    | 5½          | 5    | 9            | 6     | 10           | 6     | 12           | 12     | 12          | 12     | 15           | 18     | 16           | 21     |

that the gyratory is a machine of greater weight, capacity, and h.p. consumption than the Blake, for the same sized feed and product. Continuity of action is claimed as the reason for

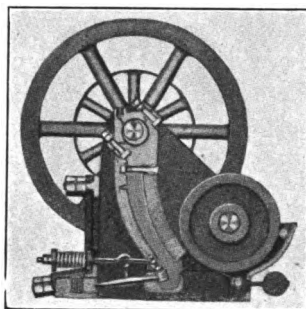


FIG. 69.—Roll-jaw crusher.

economy of power with the gyratory. Floor space is about the same for either type, but there is an economy in height in favor

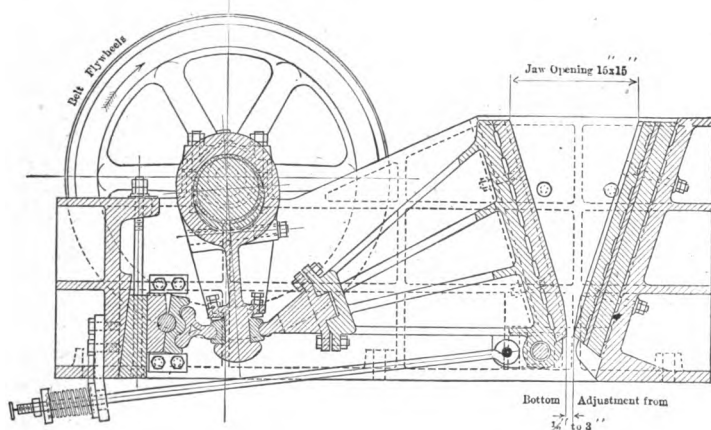


FIG. 70.—Marathon crusher.<sup>42</sup>

of the Blake. The gyratory product is more evenly cubical than that of the Blake. Wear is less on jaw-crusher plates than on gyratory concaves; and inability to reverse liners in the latter

type is a disadvantage which results in higher renewal costs. Repairs are easier made and are less frequent with the Blake than with the gyratory crusher.

**Advantages of Gyratory over Jaw Crushers** lie in lower first cost, greater automaticity (sometimes eliminating necessity for feed control) and more uniform product. The disadvantages are seen in a comparatively narrow feed opening and more complicated construction. For coarse crushing and very large output the gyratory machine has been widely adopted.

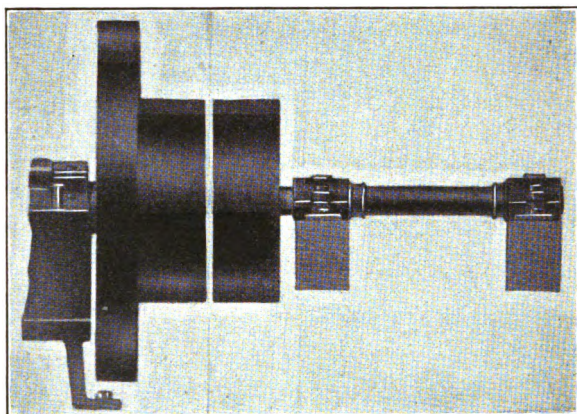


FIG. 71.—Idle pulley arrangements for crusher.

A **Roll-Jaw Crusher**, designed especially for handling sticky or easily caked material, is illustrated in Fig. 69, from which the operation of this type of machine may be understood.

The **Marathon Crusher** (Fig. 70) operates with a triangular toggle. The motions of crushing and freeing the jaw faces reciprocate in both the upper and lower portions of the movable jaw. The latter is supported by shaft and bearings.

**Crusher Idler Pulleys** in small plants, where several duties are sometimes allocated to one man, are usually a source of trouble as a result of insufficient attention to lubrication when the machine is out of action. To obviate the attention needed in this connection the arrangement shown in Fig. 71 is suitable.

The loose pulley is keyed to an independent shaft and supported on ordinary bearings. There is no connection between

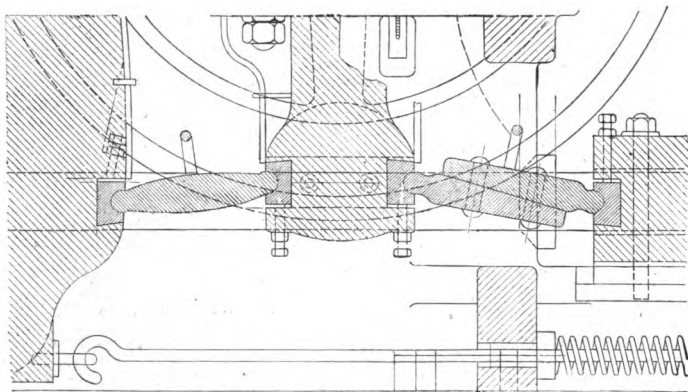


FIG. 72.—Shearing toggle for jaw crushers.<sup>7</sup>

the two pulleys, and no difficulty in “striking” the belt from one to the other.

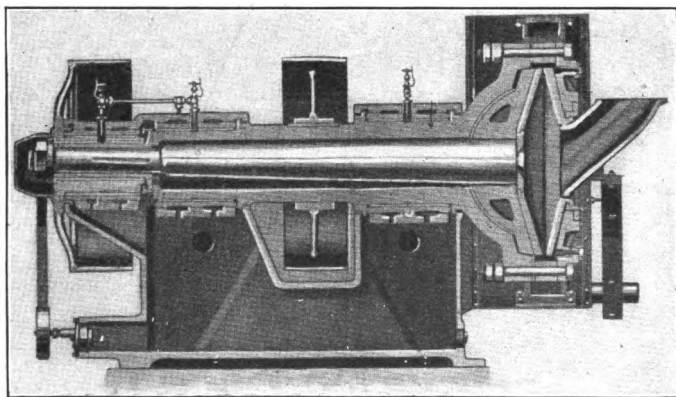


FIG. 73.—36" and 48" Symons disc crusher (sectional view).<sup>43</sup>

An effective **Method of Preventing Damage** to jaw-crusher plant and attendant machinery when steel or other unbreakable material finds its way between the jaws is shown in Fig. 72. The

rear toggle consists of two separate pieces, which are lap-jointed in the manner shown, and riveted together so that any abnormal strain put upon them will result in the shearing of the rivets. In the case of gyratory crushers a flange coupling connected with two or more soft-iron bolts in the driving countershaft will serve the same purpose. These methods have been largely adopted in Western Australia.

In the **Symons Disc Crusher** (Fig. 73) the comminution of the ore takes place in the double concavity formed by two hollowed manganese-steel discs. These discs rotate in the same direction and at the same speed, and are supported at an angle to each other. The material is fed centrally between the discs, and is thrown by centrifugal force toward the periphery, where it is crushed. Discharge of ground material takes place in the same direction and is materially aided by the centrifugal action. The ore as it is crushed travels toward an increasing discharge area, thus obviating the lowering of efficiency due to chokeage often occurring in other crushing machines. Details of construction, operation, and approximate capacity are given in Table XXXIII.

TABLE XXXIII.—SYMONS DISC CRUSHER DATA<sup>43</sup>

| Size of crusher.....                                               | 18"                                | 24"                                  | 36"                                  | 48"                                      |
|--------------------------------------------------------------------|------------------------------------|--------------------------------------|--------------------------------------|------------------------------------------|
| Shipping weight.....                                               | 5,600 lb.                          | 8,500 lb.                            | 23,500 lb.                           | 39,000 lb.                               |
| Size of feed opening.....                                          | 1½"                                | 2½"                                  | 3½"                                  | 6½"                                      |
| Minimum exit opening and tons per hour for best results.....       | ¾", 5-8                            | ¾", 12-15                            | ¾", 25-30                            | 1", 45-60                                |
| Minimum capacity in tons per hour when crushing to size given..... | ¾", 8-10<br>¾", 10-12<br>1", 12-15 | ¾", 18-20<br>1", 20-25<br>1½", 25-30 | 1", 30-45<br>1½", 45-60<br>2", 50-60 | 1½", 60-80<br>2", 80-100<br>2½", 100-120 |
| R.p.m. main pulley.....                                            | 200                                | 200                                  | 133                                  | 100                                      |
| R.p.m. eccentric pulley.....                                       | 450                                | 400                                  | 300                                  | 250                                      |
| Size of pulleys, in.....                                           | 28×8                               | 34×10                                | 44×14                                | 54×16                                    |
| Horse power required.....                                          | 12 to 18                           | 18 to 25                             | 30 to 40                             | 50 to 65                                 |

**Swing-Hammer Pulverizers** are high-speed machines and have only a limited application in ore-dressing operations. Various types are constructed in which the action of impact between hammer and rock occurs either on the up or down stroke of the

hammer. Figure 74 illustrates a typical machine of the latter type, but it is only suitable for the reduction of a friable ore.

**Hammer-Pulverizer Operation** on limestone indicates that the feed should be of a diameter not exceeding 3 in. Softer material

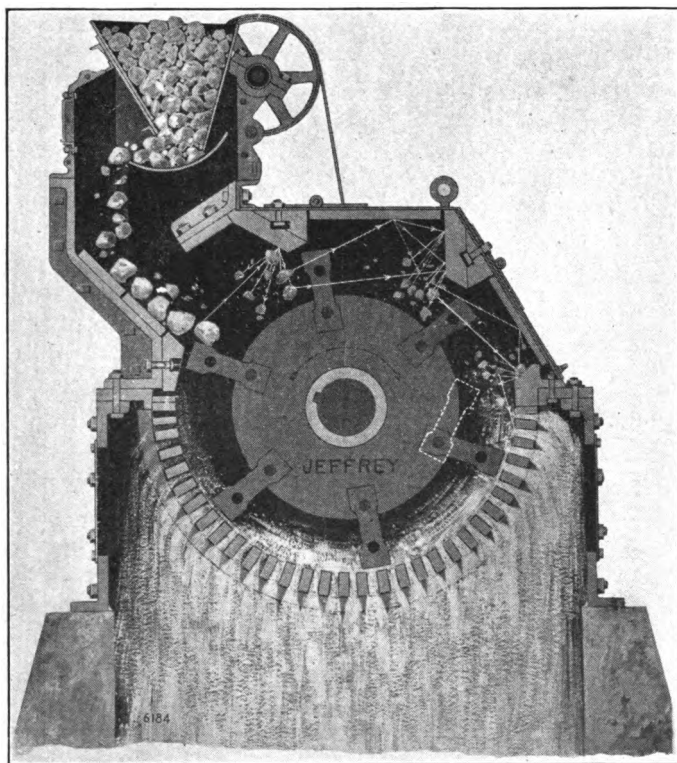


FIG. 74.—Jeffrey swing-hammer pulverizer.<sup>44</sup>

can be successfully handled by this machine in larger lumps. A type of semi-circular grizzly is used to regulate discharge, and the openings may vary from  $\frac{1}{8}$  in. to 1 in. A statement of comparative capacities for Jeffrey pulverizers on limestone and coal is given in Table XXXIV.

TABLE XXXIV.—JEFFREY SWING-HAMMER PULVERIZER OPERATION<sup>44</sup>  
Limestone

| Diameter,<br>in. | Width,<br>in. | Approx.<br>h.p. | Approx.<br>weight,<br>lb. | Speed          | Approximate capacity per hour                            |
|------------------|---------------|-----------------|---------------------------|----------------|----------------------------------------------------------|
| 24               | 12            | 15              | 2,200                     | 1,200 to 1,500 | 1 to 2 tons limestone, etc., $\frac{1}{8}$ " openings.   |
| 24               | 18            | 25              | 2,700                     | 1,200 to 1,400 | 2 to 3 tons limestone, etc., $\frac{1}{8}$ " openings.   |
| 30               | 24            | 40              | 4,500                     | 1,100 to 1,300 | 4 to 5 tons limestone, etc., $\frac{1}{8}$ " openings.   |
| 36               | 24            | 60              | 6,400                     | 1,000 to 1,200 | 8 to 10 tons limestone, etc., $\frac{1}{8}$ " openings.  |
| 36               | 30            | 75              | 7,500                     | 1,000 to 1,100 | 12 to 15 tons limestone, etc., $\frac{1}{8}$ " openings. |
| 42               | 24            | 75              | 8,500                     | 900 to 1,000   | 12 to 15 tons limestone, etc., $\frac{1}{8}$ " openings. |
| 42               | 36            | 100             | 9,500                     | 900 to 1,000   | 15 to 20 tons limestone, etc., $\frac{1}{8}$ " openings. |
| Coal             |               |                 |                           |                |                                                          |
| 30               | 24            | 35              | 4,300                     | 1,100 to 1,200 | 20 to 25 tons run mine coal, $\frac{1}{4}$ " to dust.    |
| 36               | 30            | 70              | 7,300                     | 1,000 to 1,100 | 50 to 60 tons run mine coal, $\frac{1}{4}$ " to dust.    |
| 42               | 24            | 70              | 8,000                     | 900 to 1,000   | 50 to 60 tons run mine coal, $\frac{1}{4}$ " to dust.    |
| 42               | 36            | 80              | 9,000                     | 900 to 1,000   | 70 to 75 tons run mine coal, $\frac{1}{4}$ " to dust.    |
| 42               | 48            | 110             | 16,000                    | 800 to 900     | 90 to 100 tons run mine coal, $\frac{1}{4}$ " to dust.   |

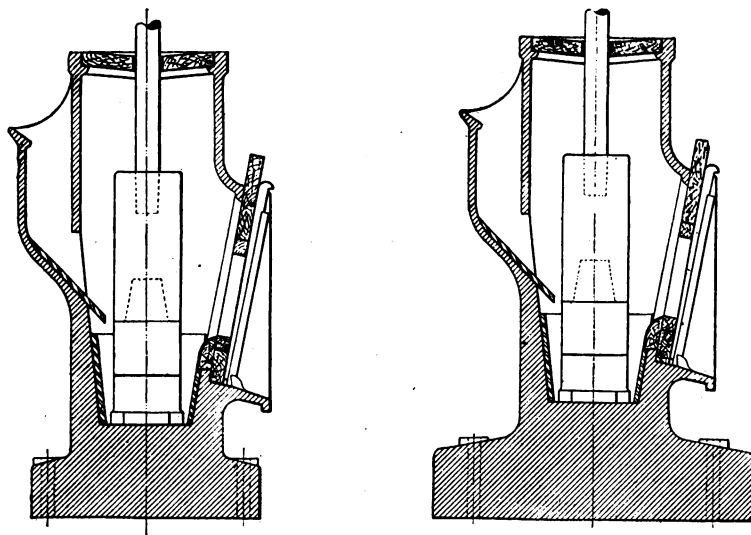


## SECTION VIII

### STAMP MILLING

**Stamp Mills** are made in a wide variety of types. The number of stamps operating in a single mortar box may be either one, two, three, or five. The latter number forms the usual unit.

**Mortar Boxes** set on concrete foundations require a wider base than for a wooden foundation. Types are illustrated in

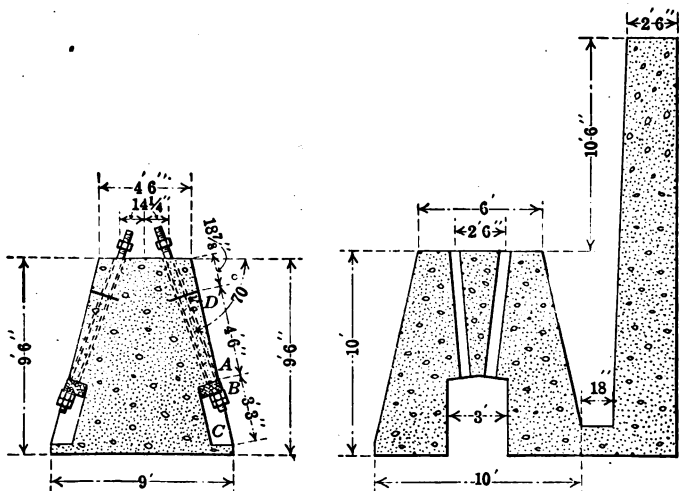
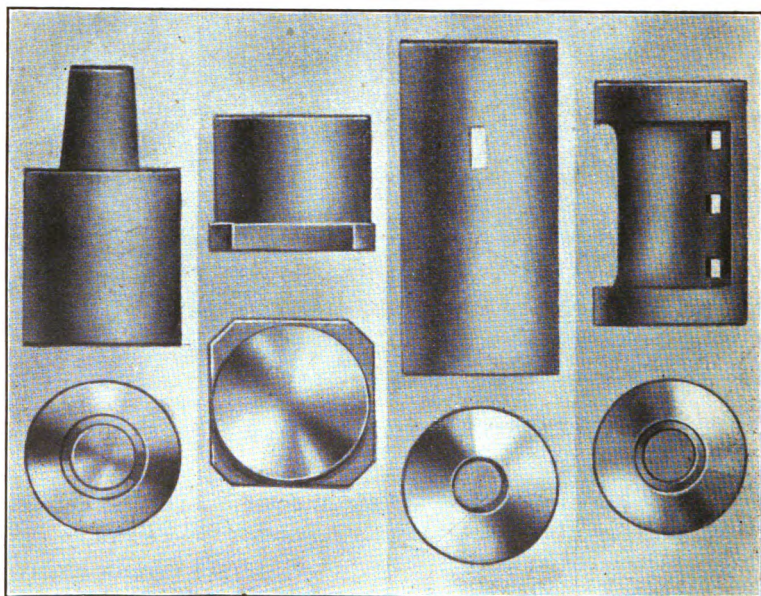


For wooden foundation or iron sub-base.

For concrete foundation.

FIG. 75.—Mortar boxes.<sup>16</sup>

Fig. 75. Single-discharge boxes are in common use, the double-discharge type (back and front), having been generally discarded whenever adopted. Open-front boxes permit greater freedom in changing shoes and dies, and in carrying out general

FIG. 76.—Types of mortar foundations.<sup>46</sup>

Shoe

Die

Bosshead

Tappet

FIG. 77.—Stamp-mill parts.

repair work, and were introduced to facilitate the removal of the bulky bosshead used in heavy-stamp mills.

**Concrete** has now generally superseded wood for mortar-box foundations. Its rigidity, low first cost, neat appearance, and durability are in its favor. Concrete mortar blocks require to be massive, with a wide base, and with accessible bolt holes: Types shown in Fig. 76 are commonly adopted.

**Stamp-Mill Parts** are illustrated in Figs. 77 and 78. **Shoes** and **Dies** are made of a variety of materials, from mixtures of

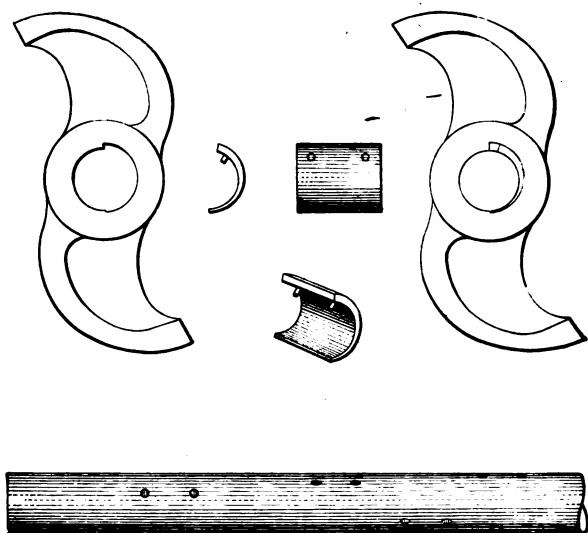


FIG. 78.—The Blanton cam.<sup>11</sup>

scrap iron and steel, cast locally on the property, to the hardest chrome steel. Local conditions and economic considerations should decide the matter of suitability of material used. **Tappets** and **Cams** are usually made of cast steel, **Camshafts** of hammered iron, and **Stems** of the best refined mild steel. **Mortar-Box Liners** are preferably made of the hardest material possible, and manganese steel is usually adopted. A section of a stamp

battery showing the position of the various parts is given in Fig. 79.

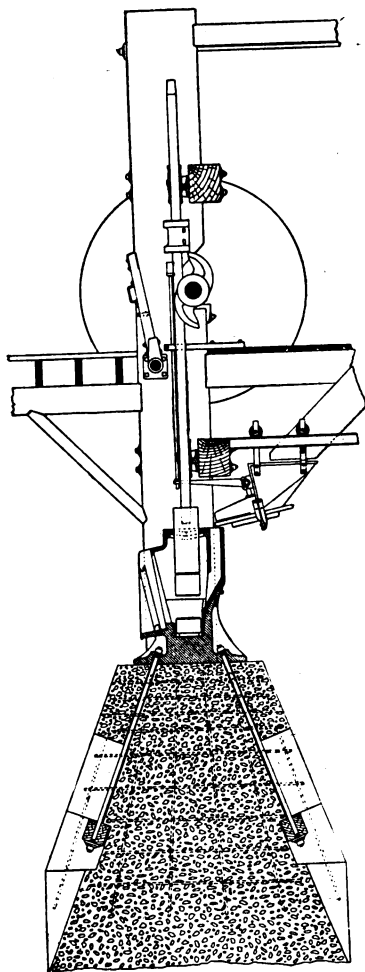


FIG. 79.—Details of stamp-mill on concrete foundation.<sup>12</sup>

**Cam Lifting Surface** is usually in the form of an involute. In the ordinary design the curve is formed by selecting a point on the outer circumference of a circle representing the hub periphery, and with a radius of length  $ab$ , about 1.2 times the diameter of the circle, the involute is formed as shown in Fig. 80.

**Heavy Stamps** require a modification of cam involute design. Fig. 81 shows the Behr type which is used in South Africa. A considerable portion of the cam surface is circular in form, the remainder being of the ordinary involute design. An increased drop-height is obtained with this type, with an even curve surface.

The **Blanton Self-Tightening Cam** (Fig. 78) relies on a brass taper bushing carrying studs. The latter pocket into holes bored in the camshaft and merely serve to keep the wedge in position. There is no shearing strain on these pins. Cam fastenings of this or a similar type are universally used in stamp mills.

**Compensating Weights** (Fig. 82) to allow for decrease of effective stamp weight as a result

of shoe wear are usually made to clamp on the stem just above the bosshead. Dimensions are governed by stem and bosshead sizes, and weight required.

**Individual False Dies** are used to raise the die, when worn down, to the proper level below the screen discharge. These

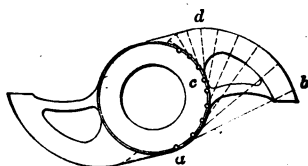


FIG. 80.—Cam involute design.

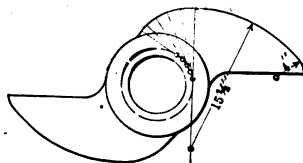


FIG. 81.—Behr-cam involute design.<sup>46</sup>

may be cast of any desirable thickness, of a similar size to the die bottom, and are preferred to the single false die sometimes supplied with mortar boxes. Old dies, worn to an even face, are sometimes used.

The **Height of Discharge** measured from the highest die level to the lowest screen level is regulated, when necessary, by the use of **Chuck Blocks**. These are made of wood of the same length and thickness as the screen frame, and faced inside with steel plate to withstand the scouring action of the pulp.

**Battery Framing** is usually of the back-knee type. The king-posts are tied to the ore bins by means of a wooden stay held in position either by long bolts or attached by means of angle-plates at each end. The countershaft driving the mills is placed on the streak sills behind the battery. Figure 83 illustrates the usual arrangement of battery timbers and the method of driving.

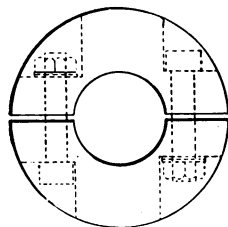


FIG. 82.—Top view of stamp-mill compensating weight.

The principal battery timbers, known as **King Posts**, standing at either end of the mortar box, are connected with concrete foundations by means of cast-iron shoes (Fig. 84). The use of metal posts in place of battery timbers has not proved generally

successful. This is usually due to breakage, consequent on vibration where heavy stamps are used.

**Camshaft Bearings** (Fig. 85) are seldom provided with more than canvas dust covers. Bearing metal is also rarely used. Such bearings are made of cast iron turned to fit the camshaft.

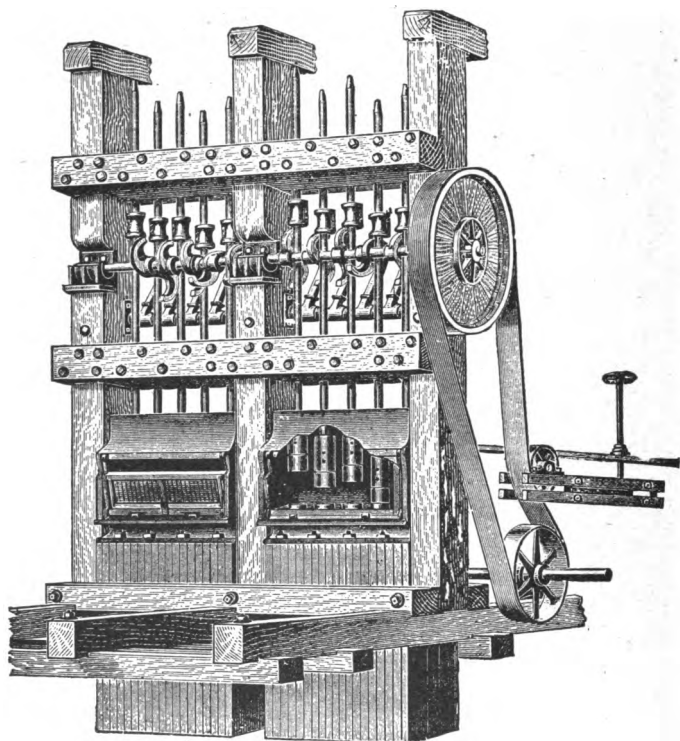
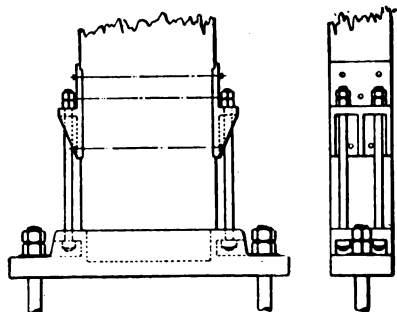
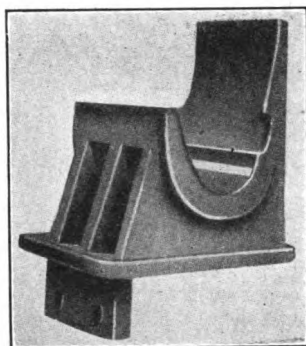
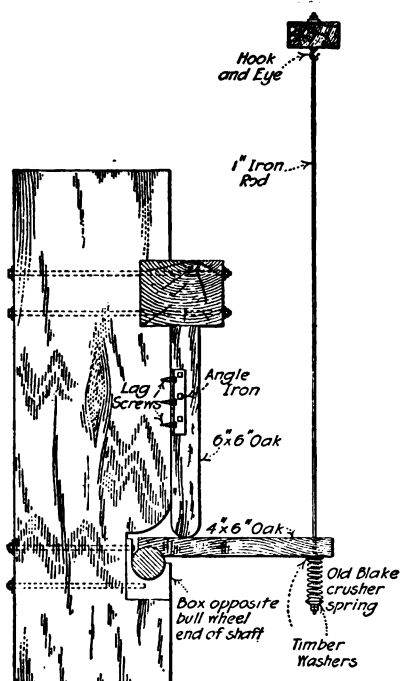


FIG. 83.—Battery framing.<sup>18</sup>

**Tappets** with one gib and two or three keys are used for light stamps. Stamps whose effective falling weight is beyond 1500 lb. are generally provided with double-gib, three- or four-key tappets.

The faces of **Gibs** used in wedging the tappet on the stem should have a curve of slightly smaller diameter than the stem.

FIG. 84.—Battery-post shoe.<sup>16</sup>FIG. 85.—Cam-shaft bearing.<sup>16</sup>FIG. 86.—Cam-shaft damper.<sup>47</sup>

In addition, it is advisable to channel or counterbore the opposite side of the tappet so as to give additional points of friction contact.

The **Camshaft Damper**, illustrated in Fig. 86, consists of two short pieces of oak, an iron rod, and any suitable spring. The adoption of this device is said to have reduced vibration of the camshaft, crystallization and fracture of the steel, and damage to camshaft bearings.

**Stamp-Stem Guides** in old mills are often made of wood, but the individual-metal type is now almost universally adopted in new mills. The guide illustrated in Fig. 87 has interlocking bushings in halves, and the guide frames are made with tapered

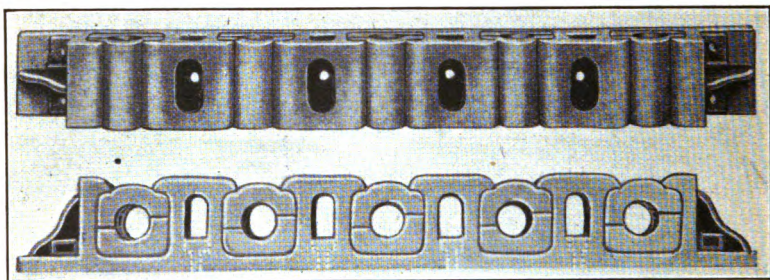


FIG. 87.—Metal stamp-stem guides.<sup>18</sup>

sockets. Stamp stems may be changed without loosening nuts or removing bolts.

A **Finger Jack** is used in conjunction with a **Cam Stick** to "hang up" any particular stamp. The cam stick, generally made of old belting with a wooden handle, is of sufficient thickness when placed between cam and tappet to raise the latter so that the finger jack may be thrown in against the stem to support the tappet above cam action.

Correct **Order of Drop** in a five-stamp mill is a matter of individual opinion among operators. The 1-3-5-2-4 order is largely adopted, but an evenner discharge and higher battery output have been claimed in the use of the 1-5-2-4-3 sequence.

The **Nissen Stamp** (Fig. 88) operates in a single mortar box and is especially adapted for high-duty performance on hard or



medium-hard ores. The screening is arranged to encompass the die and extends around it for the greater part of its circumference.

Exhaustive data dealing with the operation of **Heavy Stamp**

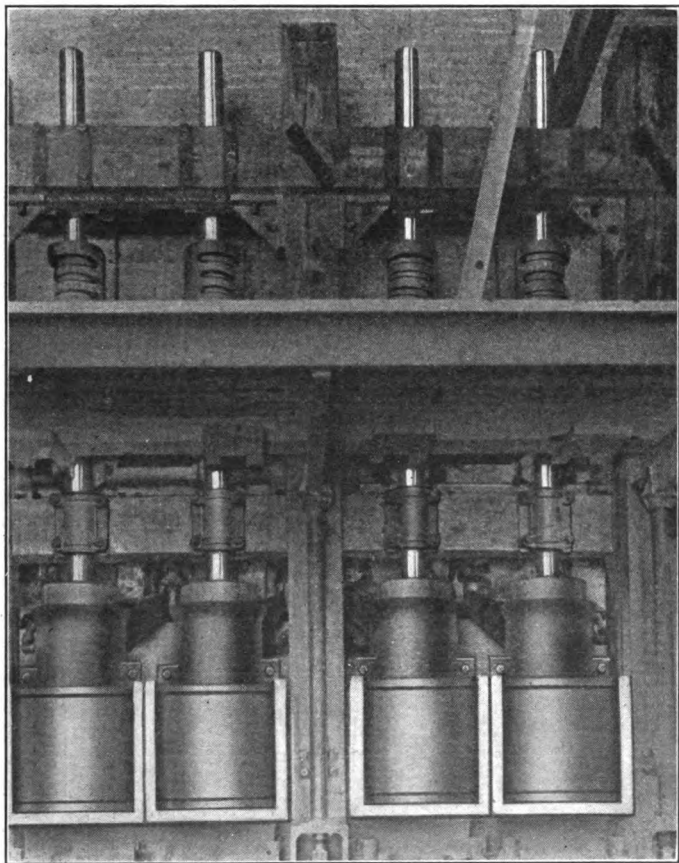


FIG. 88.—A Nissen-stamp mill.

**Mills** are given in Table XXXV and refer to the results of a series of tests made to compare the work of the **Nissen Stamp** with that of an ordinary five-stamp battery at the City Deep Mine, South Africa, in 1911. Relative mechanical values of the

TABLE XXXV.—COMPARATIVE TESTS BETWEEN NISSEN AND ORDINARY HEAVY GRAVITY FIVE-STAMP MILLS<sup>1a</sup>

| Test number.....                                          | 1a            | 1b                     | 2a            | 2b                     | 3a       | 3b                     | 4a       | 4b                     | 5a       | 5b                     |
|-----------------------------------------------------------|---------------|------------------------|---------------|------------------------|----------|------------------------|----------|------------------------|----------|------------------------|
| Number of stamps and kind..                               | 4 Nissen      | 2-5 stamp<br>batteries | 4 Nissen      | 2-5 stamp<br>batteries | 4 Nissen | 2-5 stamp<br>batteries | 4 Nissen | 2-5 stamp<br>batteries | 4 Nissen | 2-5 stamp<br>batteries |
| Weight of stamps in lb.....                               | 1922          | 1863                   | 1927          | 1859                   | 2245     | 1855                   | 1993     | 1775                   | 1991     | 1773                   |
| Number of drops per minute                                | 103           | 100                    | 103           | 100                    | 103      | 100                    | 103      | 100                    | 103      | 100                    |
| Height of drop, in.....                                   | 8½            | 8½                     | 8½            | 8½                     | 8½       | 8½                     | 8½       | 8½                     | 8½       | 8½                     |
| Height of discharge, in.....                              | 2½            | 2½                     | 2             | 2½                     | 2        | 2½                     | 2½       | 2½                     | 2½       | 2½                     |
| Class of screen.....                                      | Tyler ton-cap | Tyler ton-cap          | Tyler ton-cap | Tyler ton-cap          | sq. mesh | 14 (0.08)              | sq. mesh | wire                   | sq. mesh | wire                   |
| Mesh of screen.....                                       | 9             | 9                      | 9             | 9                      | ¾"       | ¾"                     | 9        | 9                      | ¾"       | ¾"                     |
| Width of aperture, in.....                                | 0.205         | 0.205                  | 0.205         | 0.205                  | 0.375    | 0.375                  | 0.277    | 0.277                  | 0.375    | 0.375                  |
| Length of aperture, in.....                               | 0.536         | 0.536                  | 0.536         | 0.536                  | 0.375    | 0.375                  | 0.277    | 0.277                  | 0.375    | 0.375                  |
| Tons dry ore crushed.....                                 | 180.86        | 192.75                 | 180.25        | 192.12                 | 193.88   | 206.66                 | 185.32   | 194.52                 | 185.7    | 191.2                  |
| Total run in hours.....                                   | 44.33         | 25.33                  | 39.0          | 23.166                 | 31.70    | 21.83                  | 37.29    | 22.28                  | 29.52    | 18.85                  |
| Tons per stamp per 24 hours                               | 24.47         | 18.26                  | 27.73         | 19.90                  | 36.69    | 22.72                  | 29.81    | 20.95                  | 37.74    | 24.34                  |
| H.p. per stamp.....                                       | 4.09          | 4.21                   | 4.09          | 4.21                   | 4.95     | 4.21                   | 4.23     | 4.65                   | 4.23     | 4.65                   |
| H.p.-hours per ton crushed..                              | 4.0           | 5.5                    | 3.56          | 5.06                   | 3.24     | 4.45                   | 3.41     | 5.32                   | 2.71     | 4.56                   |
| Lb. ore crushed per pound<br>falling weight per day.....  | 25.33         | 19.6                   | 28.72         | 21.412                 | 32.68    | 24.49                  | 29.91    | 23.60                  | 37.91    | 27.45                  |
| Water: ore weight.....                                    | 5.4:1         | 2.7:1                  | 4.2:1         | 2.4:1                  | 3.1:1    | 2.15:1                 | 3.3:1    | 3.3:1                  | 3.03:1   | 3.26:1                 |
| Consumption metal in shoes<br>in pounds per ton crushed.. | 0.129         | 0.145                  | 0.139         | 0.24                   | 0.198    | 0.187                  | 0.147    | .....                  | 0.112    | 0.08                   |

TABLE XXXVI.—DIMENSIONS AND WEIGHTS OF STAMP-BATTERY PARTS<sup>16</sup>

|                                            |          |          |          |          |          |          |         |
|--------------------------------------------|----------|----------|----------|----------|----------|----------|---------|
| Weight of stamp, lb.....                   | 850      | 1000     | 1050     | 1250     | 1509     | 1600     | 1800    |
| Shoe, dia. of body by height, in.....      | 8½ × 8   | 9 × 8    | 9 × 8    | 9 × 10   | 9 × 12   | 9 × 12   | 9 × 12  |
| Shoe, weight, lb.....                      | 150      | 170      | 170      | 200      | 242      | 242      | 242     |
| Die, dia. of body, in.....                 | 8¾       | 9¼       | 9¼       | 9¼       | 9¼       | 9¼       | 9¼      |
| Die, 6 in. high, weight, lb.....           | 106      | 122      | 122      | 122      | 122      | 122      | 122     |
| Die, 7 in. high, weight, lb.....           | 121      | 140      | 140      | 140      | 140      | 140      | 140     |
| Die, 8 in. high, weight, lb.....           | 136      | 157      | 157      | 157      | 157      | 157      | 157     |
| Bosshead, dia. by height, in.....          | 8½ × 18  | 9 × 18   | 9 × 19   | 9½ × 22  | 9¼ × 26½ | 9¼ × 30½ | 9¼ × 37 |
| Bosshead, weight, lb.....                  | 232      | 270      | 285      | 350      | 420      | 498      | 621     |
| Tappet, 3 keys, dia. by height, in.....    | 9 × 12   | 9½ × 14  | 9½ × 14  | 9¼ × 15  | 9½ × 15  | 9½ × 15  | 9½ × 17 |
| Tappet, weight, lb.....                    | 136      | 155      | 155      | 170      | 185      | 185      | 212     |
| Cam, dia. of hub, in.....                  | 12       | 12       | 12       | 13½      | 14       | 14       | 14      |
| Cam, weight, not less than, lb.....        | 180      | 200      | 200      | 225      | 235      | 235      | 240     |
| Stem, dia. by length, in.....              | 3½ × 168 | 3⅝ × 168 | 3½ × 168 | 3¾ × 174 | 4 × 186  | 4 × 192  | 4 × 204 |
| Stem, weight, lb.....                      | 365      | 426      | 455      | 545      | 661      | 683      | 725     |
| Camshaft, dia. (length 14½ ft.), in.....   | 5¾       | 5¾       | 6        | 7        | 7        | 7¼       | 7¼      |
| Camshaft, weight, lb.....                  | 1120     | 1280     | 1400     | 1915     | 1915     | 2050     | 2050    |
| Pulley for camshaft, dia. by face, in..... | 72 × 14  | 78 × 16  | 84 × 16  | 84 × 18  | 84 × 20  | 84 × 22  | 84 × 24 |

products were obtained by screening analyses and calculation by means of Stadler's energy-unit system, based on Kick's Law, with the result that the relative efficiency of the Nissen was calculated at 0.25 and that of the ordinary stamp at 0.19, an advantage of 35 per cent. in favor of the Nissen.

**Dimensions and Weights of Stamp-Battery Parts** (U. S. A. practice) may be found in Table XXXVI. Further details

**TABLE XXXVII.—WEIGHT AND SIZE OF MILL PARTS FOR VARIOUS WEIGHTS OF STAMPS IN SOUTH AFRICAN MINES**

|                           | Simmer & Jack<br>Prop. | Simmer East | City Deep              |
|---------------------------|------------------------|-------------|------------------------|
| Weight of stamp, lb. .... | 1250                   | 1550        | 2000                   |
| Weight of shoe, lb. ....  | 160                    | 286         | 290                    |
| Head, lb. ....            | 365                    | 376         | 872                    |
| Stem, lb. ....            | 580                    | 726         | 556                    |
| Tappet, lb. ....          | 145                    | 250         | 282                    |
| Size of shoe, in. ....    | 9 × 9                  | 9¼ × 14     | 9 × 14                 |
| Head, in. ....            | 9 × 18                 | 9¼ × 24     | 9½ × 50                |
| Stem, in. × ft. ....      | 3½ × 18                | 4 × 17      | 4 × 13                 |
| Tappet, in. ....          | 9¼ × 13                | 9⅝ × 13     | 9 × 20                 |
| Diameter of camshaft, in. | 6½                     | 6½          | 7<br>hollow<br>1½ bore |

**TABLE XXXVIII.—STAMP-MILLING DATA OF AMERICAN PRACTICE<sup>49</sup>**

|                  | Tons<br>milled<br>per 24<br>hr. | Number<br>of<br>stamps | Run-<br>ning<br>weight,<br>lb. | Dis-<br>charge<br>aper-<br>ture,<br>in. | H.p.-<br>hours<br>per ton<br>milled | Stamp-<br>ing cost<br>per ton<br>milled,<br>cents | Sizing                 |                        |
|------------------|---------------------------------|------------------------|--------------------------------|-----------------------------------------|-------------------------------------|---------------------------------------------------|------------------------|------------------------|
|                  |                                 |                        |                                |                                         |                                     |                                                   | Per<br>cent.,<br>— 100 | Per<br>cent.,<br>— 200 |
|                  |                                 |                        |                                |                                         |                                     |                                                   | Inches                 |                        |
|                  |                                 |                        |                                |                                         |                                     |                                                   | 0.0055                 | 0.0029                 |
| Mex. Silver Mill | 1000                            | 60                     | 1450                           | 0.371                                   | 4.8                                 | 10.0                                              | ....                   | 14.0                   |
| Nipissing        | 245                             | 40                     | 1450                           | 0.334                                   | 12.1                                | 23.8                                              | 20.3                   | 16.7                   |
| Belmont          | 500                             | 60                     | 1200                           | 0.131                                   | 7.2                                 | 20.7                                              | 28.3                   | 19.5                   |
| Silver Peak      | 500                             | 120                    | 1050                           | 0.023                                   | 13.8                                | 31.4                                              | 54.0                   | 40.0                   |
| Homestake        | 4500                            | 1020                   | 850                            | 0.022                                   | 11.0                                | 20.4                                              | 80.0                   | 60.0                   |
| Hollinger        | 585                             | 60                     | 1400                           | 0.263                                   | 8.6                                 | 16.0                                              | ....                   | 15.0                   |
| Porcupine Crown  | 150                             | 20                     | 1000                           | 0.250                                   | 6.0                                 | 14.0                                              | ....                   | 15.0                   |
| Liberty Bell     | 485                             | 80                     | 750                            | 0.041                                   | 7.8                                 | 19.1                                              | 54.0                   | 46.0                   |

TABLE XXXIX.—CANADIAN AND UNITED STATES STAMP-MILLING PRACTICE<sup>60</sup>

| Mill                   | No. stamps | Weight, lb. | Drop, in. | Drops per min. | Feed character     | Av. Size, in. | Screen used   | Regrinding machine    |
|------------------------|------------|-------------|-----------|----------------|--------------------|---------------|---------------|-----------------------|
| Goldfield Con.....     | 100        | 1050        | 7         | 108            | Alunite            | 1½            | 4 mesh        | Chilean mill          |
| Homestake.....         | 1000       | 920         | 9         | 88             | Var.               | ...           | 30-35 mesh    | Tube mills            |
| Mexican.....           | 10         | 1250        | 6         | 104            | Quartz and clay    | 2             | 4 mesh        | Chilean mill          |
| Dome.....              | 40         | 1250        | 6½        | 100            | Quartz and schist  | 1½            | 10 mesh       | Tube mills            |
| West End, Tonopah..... | 20         | (1200)      | 6½        | 101            | Quartz             | 1             | .....         | Tube mills            |
| Montana Tonopah.....   | 40         | (1300)      | 7½        | 102            | Quartz             | 2             | 25 mesh       | Tube mills            |
| Tonopah Extension..... | 30         | 1050        | 7         | 100            | Quartz             | 2             | 3 and 12 mesh | Tube mills            |
| McNamara.....          | 10         | 1400        | 8         | 98             | Quartz             | 2             | 8 and 12 mesh | Tube mills            |
| Nevada Hills.....      | 20         | 1250        | 6½        | 107            | Hard quartz        | 1½            | 8 mesh        | Tube mills            |
| Nevada Wonder.....     | 10         | 1400        | 8         | 96             | Quartz             | 2½            | ¾ in.         | Chilean and tube mill |
| North Star.....        | 40         | 1000        | 7         | 110            | Quartz             | 2             | 30-mesh       | None                  |
| Black Oak.....         | 20         | 1250        | 6         | 102            | Quartz             | 2             | 20 and 6 mesh | Tube mill             |
| Gold Road.....         | 40         | 1050        | 7         | 104            | Quartz and calcite | 2½            | 4 mesh        | Tube mills            |
| Tom Reed.....          | 20         | 1250        | 6         | 105            | Quartz             | 3             | 12 mesh       | Tube mills            |
| Vulture.....           | 20         | 1600        | 6½        | 98             | Quartz             | 2             | 40 mesh       | Pans                  |

TABLE XL.—STAMP-MILL DATA OF WESTERN AUSTRALIAN PRACTICE<sup>7</sup>

| Mine            | Weight of stamps, lb. | Wear per ton crushed |           | Screening | Dis-charge, in. | Drops        |             | Duty per stamp per 24 hours, tons |
|-----------------|-----------------------|----------------------|-----------|-----------|-----------------|--------------|-------------|-----------------------------------|
|                 |                       | Shoes, oz.           | Dies, oz. |           |                 | No. per min. | Height, in. |                                   |
| Ivanhoe.....    | 1192                  | ....                 | ....      | 15 × 15   | 2               | 104          | 7½          | 5.5                               |
| Oroya           |                       |                      |           |           |                 |              |             |                                   |
| Brown Hill...   | 1100                  | 4.26                 | 4.56      | 10 × 10   | 2               | 108          | 7¾          | 6.48                              |
| Sons of Gwalia. | 1000                  | ....                 | ....      | 20 × 20   | 3½              | 108          | 8           | 6.68                              |
| Lake View       |                       |                      |           |           |                 |              |             |                                   |
| Consols.....    | 1200                  | 4.3                  | 2.5       | 300 mesh  | 2               | 102          | 8           | 5.5                               |
| Golden          |                       |                      |           |           |                 |              |             |                                   |
| Horseshoe....   | 1274                  | 2.14                 | 3.04      | 15 × 15   | 3               | 104          | 8           | 5.5                               |
| Great Fingall.. | 1150                  | ....                 | ....      | 12 × 12   | 3               | 106          | 8           | 7.0                               |
|                 |                       |                      |           | 10 × 10   |                 |              |             |                                   |

TABLE XLI.—APPROXIMATE LIFE OF STAMP-MILL PARTS<sup>81</sup>

| Part          | Material                              | Dimensions           | Weight, lb. | Life                    |
|---------------|---------------------------------------|----------------------|-------------|-------------------------|
| Camshaft..... | Wrought iron                          | 5.36" diam.          | 1050-1085   | 4 yrs.                  |
| Cam.....      | Chrome steel                          | 2.5" face × 35" hub  | 262         | no data                 |
|               | Cast iron                             | 12" diam. × 5.75 in. | 256         | 2 yrs.                  |
|               |                                       |                      |             |                         |
| Tappet.....   | Chrome steel                          | 9" × 12"             | 150         | no data                 |
|               | Cast iron                             | —                    | 132         | 20 mths. & up.          |
| Stem.....     | Wrought iron                          | 3.125" × 15'         | 380-390     | 4 mon. bet. breakages.. |
| Bosshead..... | Cast iron                             | 9" × 18"             | 236         | 4-12 yrs. average       |
| Shoe.....     | Chilled cast iron                     | 9" × 8"              | 145         | 60-90 days              |
| Die.....      | Hard cast iron                        | 9" × 5.5"            | 110         | 30-35 days              |
| Mortar.....   | Cast iron....                         | —                    | 5500        | 3 years                 |
| Screen.....   | Cold-rolled re-annealed O. H. steel.. | 9 × 50 × 0.035       | 4           | 10-16 days              |
| Plate.....    | Lake Superior copper.....             | 4' 5" × 12' × 0.125" | 320         |                         |

NOTE.—The thickness of mortar-box ends has been since increased and a longer life is anticipated.

of South African practice in this respect are given in Table XXXVII, of American practice in Tables XXXVIII and XXXIX and of Western Australian practice in Table XL.

**Data Giving the Approximate Life of Stamp-Mill Parts** and referring to Homestake practice are given in Table XLI.

**Comparative Costs for Breaking, Crushing and Grinding** at various plants in the United States and Canada are given in Table XLII.

TABLE XLII.—COST OF ORE MILLING<sup>52</sup>

| Plant                  | Break-<br>ing, cents<br>per ton | Crush-<br>ing, cents<br>per ton | Grinding,<br>cents per ton | Method                                         |
|------------------------|---------------------------------|---------------------------------|----------------------------|------------------------------------------------|
| Homestake.....         | 6                               | 34.6                            | 25.7†                      | Stamps, pans and<br>tube mills                 |
| Goldfield Con.....     | 3.8                             | 13.4                            | 10.6 Chilean<br>16.6 tube  | Stamps, Chilean<br>and tube mills              |
| West End Con., Tonopah | 10.3*                           | 24.8                            | 49.2                       | Stamps and tube<br>mills                       |
| Hollinger.....         | 7.3                             | 18.1                            | 27.7                       | Stamps and tube<br>mills                       |
| Wonder, Nev.....       | 12.1*                           | 29.5                            | 41.8                       | Stamps, tubes and<br>high-speed Chil-<br>eans. |
| Liberty Bell.....      | 7.25                            | 19.08                           | 7.69                       | Stamps and tube<br>mills                       |
| Independence.....      | 16.33                           | 52.17†                          | ....                       | Rolls and high-<br>speed Chileans              |
| Nevada Hills.....      | 7.1                             | 24.7                            | 29.3                       | Stamps and tube<br>mills                       |
| Black Oak.....         | 5.74                            | 11.26                           | 7.99                       | Stamps and tube<br>mills                       |
| Sta. Elena.....        | ....                            | 21.22§                          | ....                       | Slow-speed Chil-<br>eans                       |
| La Union.....          | ....                            | 21.46§                          | ....                       | Slow-speed Chil-<br>eans.                      |

\* Includes conveying. † Separate treatment plant. Cost includes rolls and Chileans. ‡ Only part of material reground. Cost per ton reground. § Includes both crushing and grinding.

**Power Used for Stamp Mills** may be calculated from the diagram given in Fig. 89. For example: To find horsepower to drive a 10-stamp mill, each of 900 lb., at 90 drops per minute, follow up the vertical line commencing at 900 until it intersects one of the diagonal lines representing the height of drop. The horsepower required for a 7-in. drop will be found to be 17.5, and for an

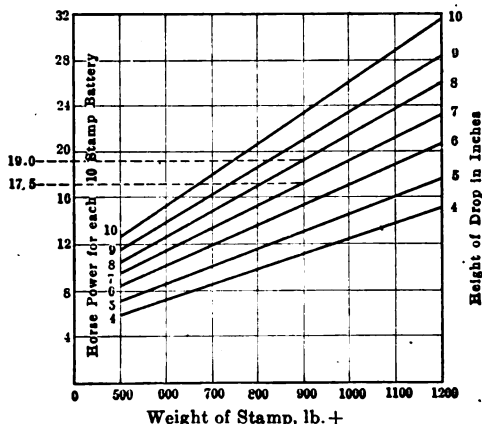


FIG. 89.—Power required for stamps, at 90 drops a minute.<sup>53</sup>

8-in. drop 19.0. These figures do not include total friction and should be multiplied by 1.2 to give an approximation of the total power required.

**The Tremain Stamp** (Fig. 90) is a self-contained unit suitable for small properties. Two stamps are used in each battery, the ends of which terminate in pistons. Steam is admitted under the piston to raise the stamp and also assists in the downward movement, thus increasing the effective stamp weight. The stamps are of comparatively light design (about 500 lb. each) and can be arranged to drop up to 200 times a minute. Discharge is through front and side screens.

**Heavy-Duty Steam Stamps** (Fig. 91) are of limited application and have only been adopted in exceptional cases. The two types



in general use on copper properties are designed on either the simple- or compound-engine system. A heavy feed is necessary, and actual duty is consequently low. A light feed predisposes toward piston-rod breakage. Del Mar quotes the usual stroke

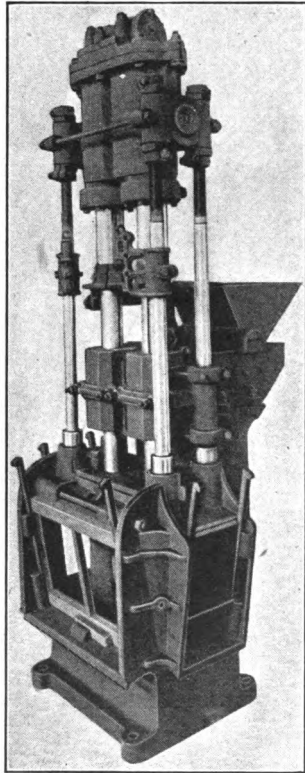


FIG. 90.—Tremain steam stamp.<sup>11</sup>

in the Lake Superior district, where these stamps are mostly used, as 24 to 25 in. on 4-in. material, giving a capacity of from 2 to 3 tons per horsepower day through a  $\frac{5}{8}$ -in. mesh screen. Shoes lasting from 4 to 7 days weigh from 780 to 800 lb. when new, and 380 to 400 lb. when rejected. Dies last 7 months to a year, and

weigh 800 lb. when new and 500 lb. when rejected. Height of discharge would seem to vary between 9 and 16 in., but the former

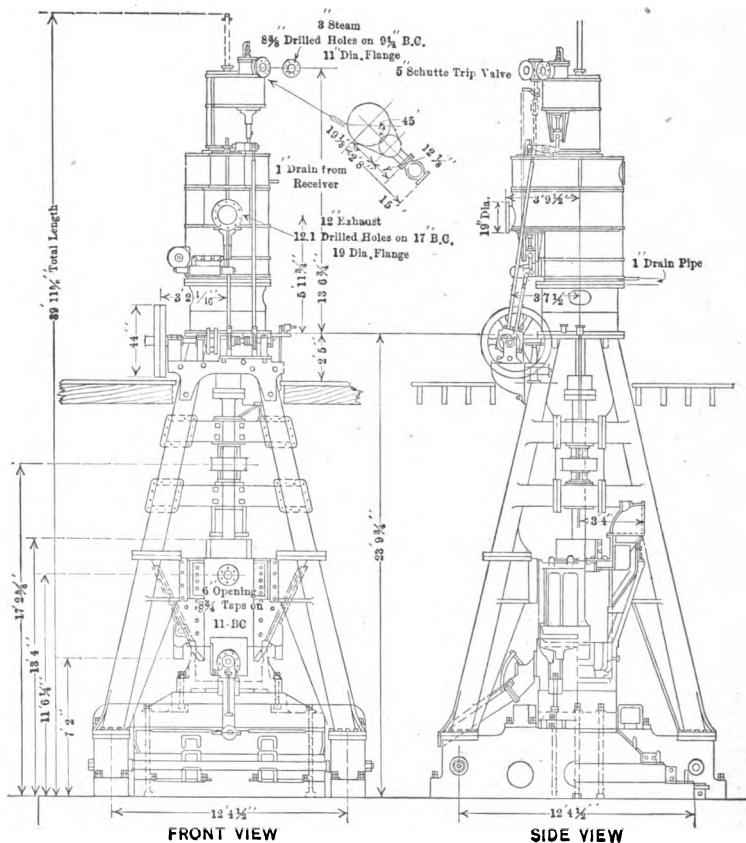


FIG. 91.—Steam stamp.

figure is probably nearer the average. The stamp head weighs 6650 lb. and the stamp is dropped with a frequency of 108 per minute.

## SECTION IX

### BALL MILLING

The **Krupp Ball Mill** (Fig. 92) consists of a narrow cylinder lined with steel plates arranged in steps. The grinding and

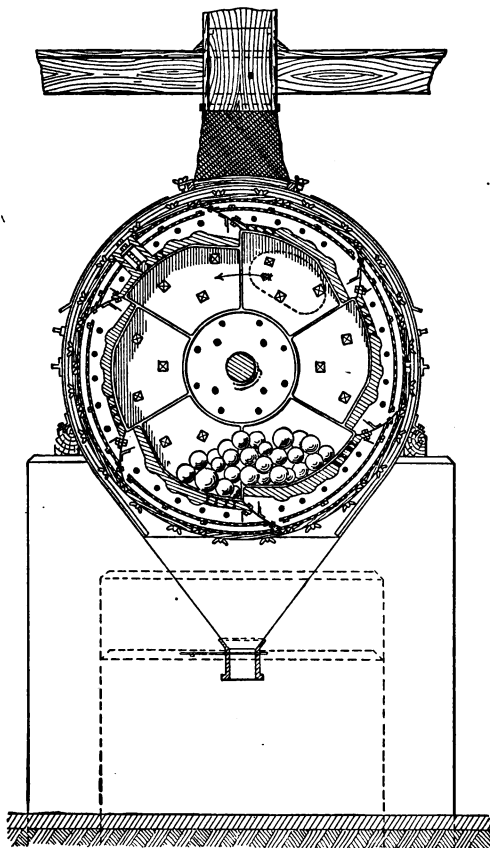


FIG. 92.—Krupp dry-crushing ball mill.

crushing are done by steel balls and the ground material passes

through tapered perforations, usually  $\frac{3}{8}$  in. to 1 in. diameter, in the grinding plates. A coarse punched screen, with holes about  $\frac{3}{4}$  in. in diameter, and placed outside the lining plates,

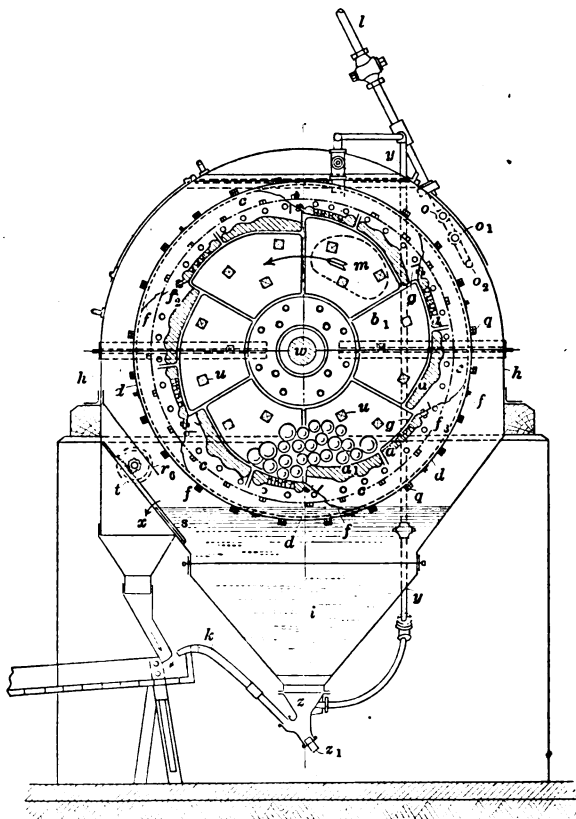


FIG. 93.—Krupp wet ball mill.

a, Perforated grinding plates; a<sub>1</sub>, Flange bolts; b, Side liners on the feed side; b<sub>1</sub>, Side liners, rear side; u, Side-plate bolts; c, Inner coarse screen; c<sub>1</sub>, Inner screen bolts; d, Fine screen (frame with wire cloth); g, Bolts for screen frame; f, Return scoops; f<sub>1</sub>, Return screen; f<sub>1</sub>, Bracket for coarse screen; h, Sheet-iron casing; i, Spitzkasten; k, Discharge nozzle; l, Supply pipe for fresh water; o, o<sub>1</sub>, o<sub>2</sub>, Roses; p, Stopcocks; s, Slide; r, Slide-racking gear; t, Hand wheel for slide-racking gear; m, Manhole; w, Main shaft; x, Overflow for slime; y, Supply pipe for ascending water; z, Discharge box; z<sub>1</sub>, Plug.

makes a further classification; and the fines pass to the wire cloth arranged in frames and covering the periphery of the mill. The oversize passes back into the mill through a perforated plate

TABLE XLIII.—KRUPP BALL MILL DATA<sup>7</sup>

| Mine                   | No. of mill | Rev. per min. | Horse power | Screening                           | Weight of balls | Tons per day |
|------------------------|-------------|---------------|-------------|-------------------------------------|-----------------|--------------|
| Associated Northern... | 5           | 25            | 16.6        | 700 × 28 (26 × 27)<br>(I. S. W. G.) | 2260–2400       | 40           |
| Kalgurli.....          | 5           | 25            | .....       | 32 × 32 × 30<br>(I. S. W. G.)       | ....            | 40           |
| Associated.....        | 5           | 25            | 16.8        | 30 × 30 × 30<br>(I. S. W. G.)       | 2240            | ...          |
| South Kalgurli.....    | 5           | 25            | .....       | .....                               | 2352            | 40           |
|                        | 8           | 24            | 57          | 700 × 26 (26 × 27)(I. S. W. G.)     | 3472            | 110          |
| Gt. Boulder Propy..... | 8           | 23            | 60          | 30 × 30 × 28<br>(I. S. W. G.)       | 4256            | 90           |

TABLE XLIV.—KRUPP BALL MILL PRODUCTS<sup>7</sup>

| Mine      | Associated Northern                     | Kalgurli                                    | South Kalgurli | Great Boulder Propy.                        |
|-----------|-----------------------------------------|---------------------------------------------|----------------|---------------------------------------------|
| Screening | 700 × 28<br>(I. S. W. G.),<br>Per cent. | 32 × 32 × 30<br>(I. S. W. G.),<br>Per cent. | Per cent.      | 30 × 30 × 28<br>(I. S. W. G.),<br>Per cent. |
| + 30      | ....                                    | .....                                       | .....          | 0.22                                        |
| + 40      | 11.6                                    | 7.96                                        | 8.80           | 5.21                                        |
| + 60      | 13.6                                    | 10.92                                       | 12.79          | 15.74                                       |
| + 80      | 10.2                                    | .....                                       | 7.01           | 6.64                                        |
| + 100     | 7.3                                     | 21.67                                       | 7.20           | 8.07                                        |
| + 120     | 2.0                                     | 6.65                                        | 3.45           | 1.67                                        |
| + 150     | 1.0                                     | 5.00                                        | 2.45           | 6.32                                        |
| – 150     | 54.3                                    | 47.80                                       | 58.30          | 56.13                                       |
|           | 100.00                                  | 100.00                                      | 100.00         | 100.00                                      |

placed beneath the steps. Data dealing with dry-crushing ball mills may be found in Table XLIII and details of typical grading analyses in Table XLIV.

**Dry Crushing with Krupp Ball Mills** has been largely practised in Western Australia on sulpho-telluride ores. The reason for the adoption of dry crushing lies in the fact that roasting follows crushing and precedes cyanide treatment.

The **Wet-Crushing Krupp Ball Mill** (Fig. 93) operates in the same manner as the dry crusher. In addition, a water spray

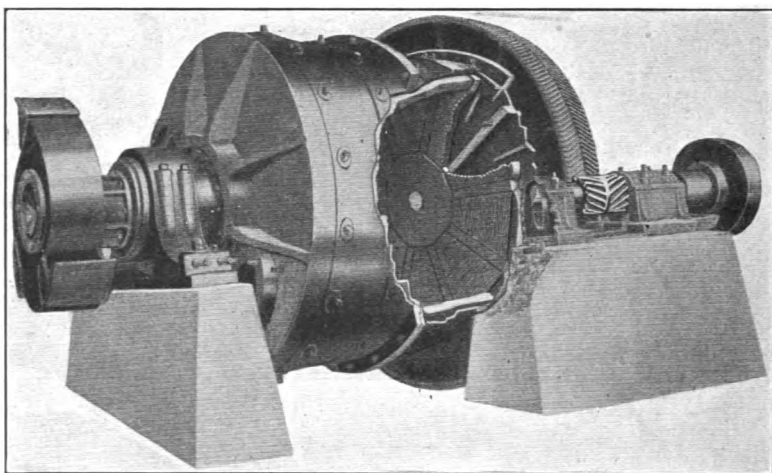


FIG. 94.—Marcy mill.<sup>84</sup>

delivers over the whole width of the fine screening just after the latter, in revolution, leaves the water surface in a trough placed underneath the mill, and forming the lower part of the casing. This trough consists of a spitzkasten with gooseneck discharge and adjustable overflow level. Water is caught up during the revolution of the mill. Crushing, screening over an exceptionally large area, and return of oversize are all performed simultaneously.

The **Marcy Mill** (Fig. 94) is of the short cylindrical type with comparatively large diameter. Feed is delivered through the usual trunnion-type feeder and delivery takes place through a

grizzly-bar screen, covering the entire discharge end of the mill. The pulp delivered into the space behind the grizzly bars is lifted with spirals and discharged through the trunnion. The mill is designed to take 3-in. or 4-in. material and crush this through  $\frac{1}{4}$  in. or  $\frac{1}{8}$  in. in one operation. With a closed-circuit return system and outside classification the mill can be arranged to crush as fine as 100 mesh. Steel-ball consumption varies from 0.5 to 1.7 lb. per ton crushed.

The usual type **Ball Mill**, used widely for reduction from crushed rock size to 80 mesh or so, consists of a short cylinder

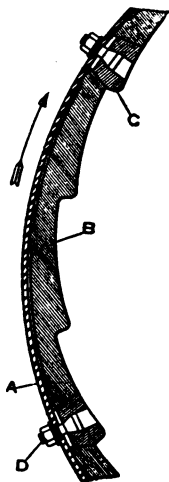
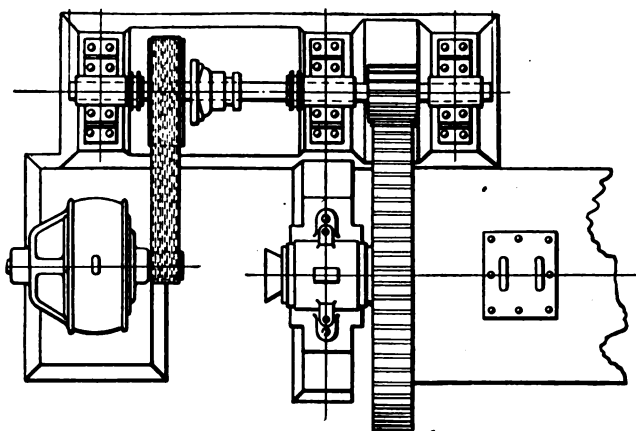
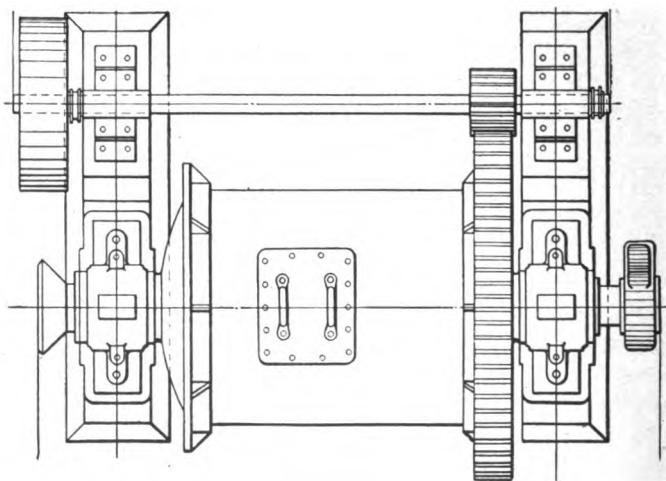


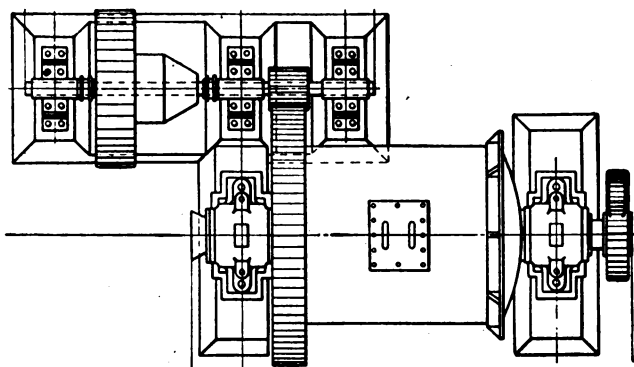
FIG. 95.—Wave-type ball-mill lining.<sup>31</sup>

driven by spur gearing. The machine is operated at maximum efficiency in closed circuit with a classifier. The wave type of lining suitable for this mill is shown in Fig. 95 and is constructed of plates with beveled ends to match the key liners *C*, the latter being alone bolted to the mill shell by means of countersunk head bolts *D*.

**Standard Sizes of Ball Mills** are given in Table XLV, with approximate capacities in Table XLVI. Methods of drive are shown in Figs. 96*a*, 96*b*, and 96*c*,

FIG. 96a.<sup>31</sup>FIG. 96b.<sup>31</sup>



FIG. 96c.—Methods of driving ball mills.<sup>31</sup>TABLE XLV.—STANDARD BALL MILLS<sup>31</sup>

| Size of mill in feet | Size of pulley in inches | Rev. per min. |      | *Horse power | †Ball charge in tons | ‡Weight of mill in pounds |
|----------------------|--------------------------|---------------|------|--------------|----------------------|---------------------------|
|                      |                          | Pulley        | Mill |              |                      |                           |
| 3 × 3                | 36 × 6                   | 168           | 32   | 6            | 0.5                  | 5,000                     |
| 3 × 4                | 36 × 6                   | 168           | 32   | 8            | 0.7                  | 5,500                     |
| 3 × 5                | 36 × 8                   | 168           | 32   | 10           | 0.9                  | 6,000                     |
| 4 × 3                | 36 × 8                   | 171           | 29   | 14           | 1.2                  | 9,500                     |
| 4 × 4                | 36 × 10                  | 171           | 29   | 18           | 1.5                  | 10,000                    |
| 4 × 5                | 36 × 10                  | 171           | 29   | 22           | 1.8                  | 10,500                    |
| 4 × 6                | 42 × 10                  | 171           | 29   | 26           | 2.1                  | 11,000                    |
| 5 × 3                | 54 × 10                  | 171           | 26   | 24           | 2.0                  | 19,000                    |
| 5 × 4                | 54 × 10                  | 171           | 26   | 30           | 2.6                  | 19,500                    |
| 5 × 5                | 54 × 12                  | 171           | 26   | 36           | 3.2                  | 20,000                    |
| 5 × 6                | 54 × 14                  | 171           | 26   | 42           | 3.8                  | 21,000                    |
| 6 × 3                | 66 × 12                  | 171           | 23   | 50           | 3.0                  | 35,000                    |
| 6 × 4                | 66 × 14                  | 171           | 23   | 62           | 4.0                  | 36,000                    |
| 6 × 5                | 66 × 16                  | 171           | 23   | 74           | 5.0                  | 37,000                    |
| 6 × 6                | 66 × 18                  | 171           | 23   | 86           | 6.0                  | 38,000                    |

\*The figures for power are for the mill while running, with balls carried up to center of mill. The power will vary with the ball charge, and the power to start the mill will be approximately double that consumed while the mill is running.

†The ball charges are approximate only, as they will vary with the thickness of the lining and the exact point at which it is found desirable to carry the balls under the particular conditions.

‡The weights given are for the mills complete with head liners and driving shaft with pinion, bearings and plain pulley; but do not include shell liners.

TABLE XLVI.—AVERAGE BALL-MILL CAPACITIES<sup>31</sup> IN TONS PER 24 HR.

|                   | 2-in. feed   |     |     |     | 1-in. feed |     |     |     | $\frac{1}{2}$ -in. feed |     |     |  |
|-------------------|--------------|-----|-----|-----|------------|-----|-----|-----|-------------------------|-----|-----|--|
| Size of mill, ft. | Mesh product |     |     |     |            |     |     |     |                         |     |     |  |
|                   | 10           | 20  | 40  | 60  | 10         | 20  | 40  | 60  | 20                      | 40  | 60  |  |
| 3 × 3             | ...          | ... | ... | ... | 15         | 12  | 8   | 5   | 13                      | 9   | 6   |  |
| 3 × 4             | ...          | ... | ... | ... | 19         | 15  | 10  | 6½  | 16                      | 11  | 8   |  |
| 3 × 5             | ...          | ... | ... | ... | 23         | 18  | 12  | 8   | 19                      | 13  | 10  |  |
| 3 × 6             | ...          | ... | ... | ... | 26         | 20  | 14  | 9½  | 21                      | 15  | 12  |  |
| 4 × 3             | 60           | 40  | 30  | 20  | 65         | 44  | 33  | 22  | 50                      | 36  | 24  |  |
| 4 × 4             | 72           | 50  | 37  | 25  | 78         | 55  | 40  | 27  | 60                      | 43  | 30  |  |
| 4 × 5             | 85           | 60  | 44  | 30  | 90         | 66  | 48  | 33  | 72                      | 52  | 36  |  |
| 4 × 6             | 95           | 70  | 50  | 35  | 105        | 77  | 55  | 38  | 85                      | 60  | 42  |  |
| 4 × 8             | 105          | 80  | 57  | 40  | 115        | 88  | 63  | 44  | 95                      | 68  | 48  |  |
| 5 × 3             | 90           | 60  | 45  | 30  | 100        | 66  | 50  | 33  | 72                      | 54  | 36  |  |
| 5 × 4             | 110          | 90  | 60  | 40  | 120        | 100 | 66  | 44  | 108                     | 72  | 48  |  |
| 5 × 5             | 125          | 110 | 75  | 50  | 135        | 121 | 83  | 55  | 130                     | 90  | 60  |  |
| 5 × 6             | 135          | 130 | 90  | 60  | 150        | 143 | 100 | 66  | 155                     | 108 | 72  |  |
| 6 × 3             | 160          | 100 | 75  | 50  | 175        | 110 | 82  | 55  | 120                     | 90  | 60  |  |
| 6 × 4             | 210          | 135 | 100 | 75  | 230        | 150 | 110 | 82  | 160                     | 120 | 90  |  |
| 6 × 5             | 250          | 165 | 125 | 100 | 275        | 180 | 137 | 110 | 200                     | 150 | 120 |  |
| 6 × 6             | 280          | 200 | 150 | 125 | 310        | 220 | 165 | 138 | 240                     | 180 | 150 |  |

The **Hardinge Mill** (Fig. 97) consists of three sections. After the usual type of trunnion bearing the mill consists of a short conical section showing a sharp drop from feed entrance to maximum mill radius. A cylindrical section of varying length then follows and toward the discharge end connects with a comparatively long and conical section sloping, at considerably less pitch than at the feed end, toward the discharge. In principle it has been claimed that a separation and grading of the balls in sizes, resulting in a corresponding graduation in the force of the crushing blow, occurred in the mill to the extent that single-passage crushing might be advocated. The successive reduction of the ore particle from rock to sand or gravel to slime was pictured as an actual achievement and as a logical departure from the normal current practice with cylindrical mills. These views have

been proved somewhat fallacious. The balls do not segregate to the extent assumed, and careful investigation has proved that the discharge sections may consist of balls of a larger average size than the medium of the balls used in the mill. A. F. Taggart (Trans. A. I. M. E., Sept., 1917) has also demonstrated that efficient Hardinge-mill operation cannot be effected by single-passage

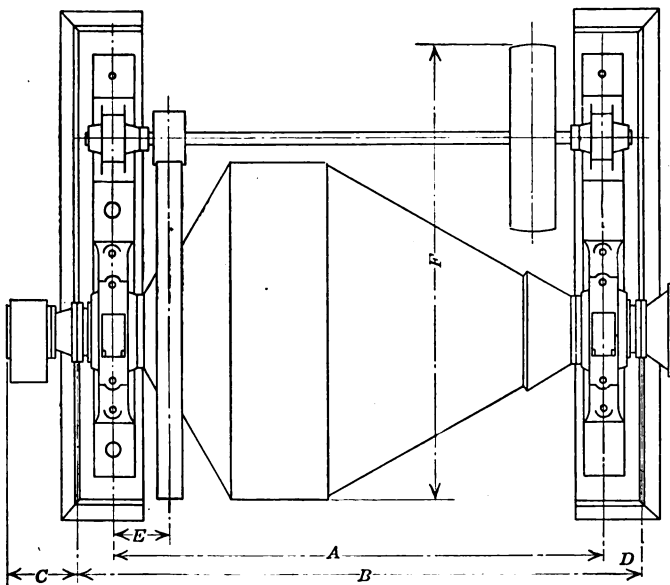


FIG. 97.—Hardinge pebble or ball mill.<sup>85</sup>

grinding, and a return classification system is indicated as desirable, as with the cylindrical mill. This would seem effectively to dispose of the "graduated blow" theory.

**Standard Sizes of Hardinge Mills** are given in Table XLVII. A summarized statement of data, consisting of the average performance of a number of these machines, is given in Table XLVIII.

TABLE XLVII.—STANDARD SIZES OF HARDINGE-MILLS<sup>85</sup>

| Mill,<br>ft. in. | A,<br>ft. in. | B,<br>ft. in. | C,<br>in. | D,<br>in. | E,<br>in. | F,<br>ft. in. | Size of<br>pulley,<br>in. | Gear<br>ratio |
|------------------|---------------|---------------|-----------|-----------|-----------|---------------|---------------------------|---------------|
| 4½×13            | 6-6           | 7-5           | 11        | 5         | 9¼        | 6-1½          | 30×10                     | 82:17         |
| 6×16             | 8-5           | 9-9½          | 13¼       | 6½        | 12½       | 8-1½          | 40×12                     | 88:17         |
| 6×16             | 8-5           | 9-10          | 16¼       | 6½        | 13¾       | 8-2½          | 42×14                     | 88:17         |
| 6×22             | 8-11          | 10-3¾         | 13¼       | 6½        | 12½       | 8-1½          | 40×10                     | 88:17         |
| 6×48             | 11-1          | 12-5¾         | 13¼       | 6½        | 12½       | 8-2½          | 42×12                     | 88:17         |
| 6×72             | 13-1          | 14-5¾         | 13¼       | 6½        | 12½       | 10-2¼         | 42×14                     | 118:17        |
| 8×22             | 11-2½         | 12-6¾         | 13¼       | 6½        | 12½       | 10-2¼         | 42×12                     | 118:17        |
| 8×22             | 11-3¾         | 12-8¾         | 16¼       | 6½        | 13¾       | 10-2¼         | 42×14                     | 118:17        |
| 9×30             | 11-10½        | 13-2¾         | 13¼       | 6½        | 12½       | 10-2¼         | 42×14                     | 118:17        |
| 8×30             | 11-11¾        | 13-4¾         | 16¼       | 6½        | 13¾       | 10-2¼         | 42×14                     | 118:17        |

NOTE: Mills marked with a subscript "s" have 15-in. dia. bearings; other 6-ft. and 8-ft. mills have 13-in. dia. bearings.

Pulley size given for 4½ ft. × 13-in. mill is for Ball Mill only; 28-in. × 8-in. pulley furnished with Pebble Mill.

For position of over-all dimensions, A to F, see Fig. 97.

TABLE XLVIII.—HARDINGE-MILL DATA<sup>84</sup>

|                                                                | 6-ft. × 16-in.<br>ball mill | 8-ft. × 22-in.<br>pebble mill |
|----------------------------------------------------------------|-----------------------------|-------------------------------|
| Average maximum size feed, mm.....                             | 44.5                        | 9.7                           |
| Average size feed, mm.....                                     | 9.0                         | 1.26                          |
| Average maximum size discharge, mm.....                        | 6.0                         | 1.5                           |
| Average size product, mm.....                                  | 0.37                        | 0.14                          |
| Average per cent.—200-mesh in discharge.....                   | 28.9                        | 37.0                          |
| Average per cent.—200 mesh in discharge—no<br>slope.....       | .....                       | 44.3                          |
| Average per cent.—200-mesh in discharge 0.5"-<br>4" slope..... | .....                       | 31.6                          |
| Reduction ratio range.....                                     | 7-67                        | 6-15                          |
| Reduction ratio, average.....                                  | 39.6                        | 0.8                           |
| Average size of discharge, mm.—no slope.....                   | .....                       | 0.10                          |
| Average size of discharge slope 0.5" to 4".....                | .....                       | 0.17                          |
| Average tonnage.....                                           | 203                         | 110                           |
| Average tonnage at no slope.....                               | .....                       | 85                            |
| Average tonnage at 0.5" to 4" slope.....                       | .....                       | 128                           |
| Average H.P.....                                               | 35.06                       | 35.6                          |
| Average ball or pebble charge, tons.....                       | 4.0                         | 4.5                           |
| Average ball or pebble cons., lb. per ton.....                 | 0.51                        | 1.94                          |
| Average per cent. water in feed.....                           | 60                          | 58.7                          |
| Average revolutions per minute.....                            | 28                          | 27.8                          |

**Variable Pulp-Level Discharge** in ball mills is provided for in the Allis-Chalmers Ball Granulator. In this machine the level of the pulp may be raised to a point approximately half-way between the trunnion and the periphery, or lowered to the periphery. This is accomplished by closing outer rings of openings behind the screens and inside the mill end (see Fig. 98). Radial ribs are provided to elevate the crushed pulp and dis-

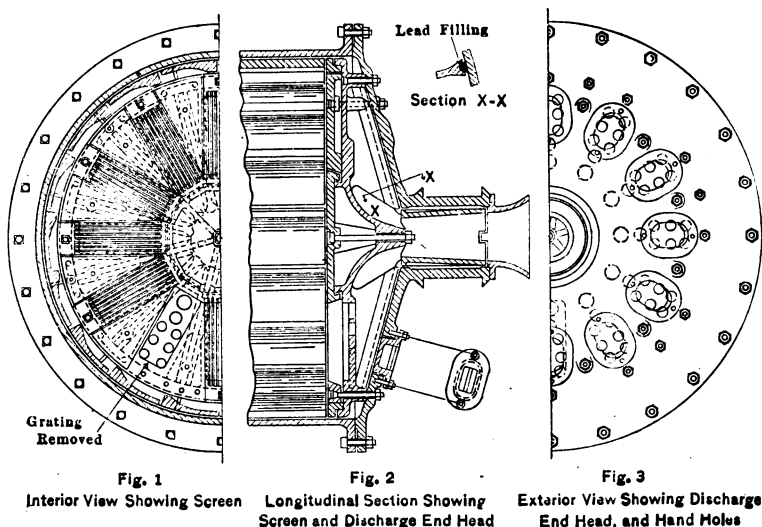


FIG. 98.—Ball-granulator variable-discharge screen.<sup>11</sup>

charge it through the trunnion. Sundry data dealing with this type of mill are given in Table XLIX.

**Screen Analysis of Ball-Granulator Products** and other information is given in Fig. 99 and refers to the operation of this type of machine at the property of the Engles Copper Mining Co., Keddie, Cal., on a hard diorite ore.

The **Abbé Spiral Discharge and Screen** for ball mills (Fig. 100) consists of a convolute with diameter decreasing toward the center line of the mill. The spiral is lined with screening in the manner shown. The material is discharged from the mill at the outer

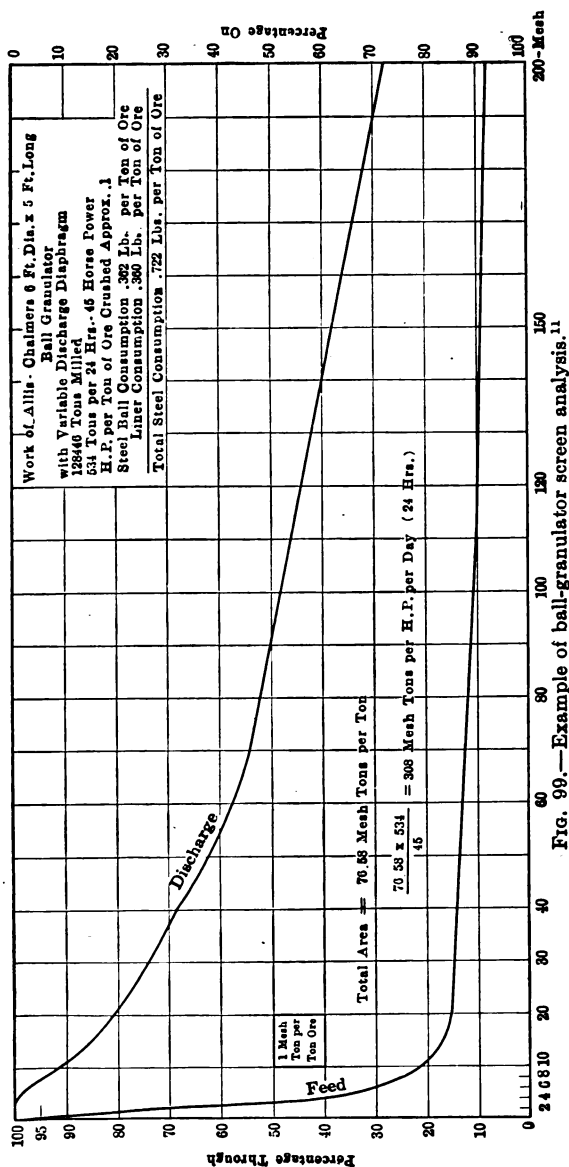
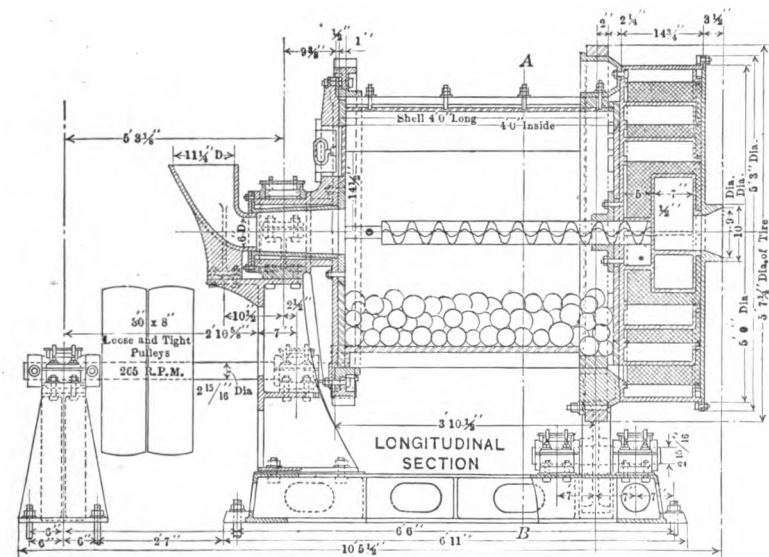
Fig. 99.—Example of ball-granulator screen analysis.<sup>11</sup>

TABLE XLIX.—STANDARD SIZES OF BALL GRANULATORS <sup>11</sup>

| Size of Mill |        | Weight of charge of balls, lb. | Capacity in tons, 3 in. to 50 mesh | Capacity in tons, 1½ in. to 20 mesh | H.p. required to run | Size of motor recommended | Revolutions per minute of mill | Speed of countershaft |                  | Size of pulley | Approximate weights complete     |                        |
|--------------|--------|--------------------------------|------------------------------------|-------------------------------------|----------------------|---------------------------|--------------------------------|-----------------------|------------------|----------------|----------------------------------|------------------------|
| Dia.         | Length |                                |                                    |                                     |                      |                           |                                | Spur gear drive       | Wuest gear drive |                | With pulley and spur gear drive* | With Wuest gear drive† |
| 4'-0"        | 4'-0"  | 5,500                          | 45                                 | 55                                  | 25                   | 40 H.p.                   | 32.5                           | 170                   | 580              | 30"×15"        | 16,500                           | 18,500                 |
| 5'-0"        | 4'-0"  | 9,000                          | 65                                 | 90                                  | 40                   | 60 H.p.                   | 28.0                           | 145                   | 430              | 54"×17"        | 29,000                           | 29,000                 |
| 5'-0"        | 5'-0"  | 11,000                         | 85                                 | 110                                 | 50                   | 75 H.p.                   | 28.0                           | 145                   | 430              | 54"×17"        | 32,000                           | 31,000                 |
| 6'-0"        | 4'-0"  | 13,500                         | 100                                | 135                                 | 60                   | 85 H.p.                   | 24.0                           | 145                   | 435              | 72"×17"        | 37,500                           | 35,000                 |
| 6'-0"        | 5'-0"  | 17,000                         | 125                                | 165                                 | 80                   | 100 H.p.                  | 24.0                           | 145                   | 435              | 72"×17"        | 40,000                           | 37,000                 |
| 6'-0"        | 6'-0"  | 20,000                         | 150                                | 200                                 | 100                  | 125 H.p.                  | 24.0                           | 145                   | 435              | 72"×17"        | 42,000                           | 39,500                 |
| 7'-0"        | 5'-0"  | 23,000                         | 170                                | 225                                 | 110                  | 125 H.p.                  | 20.0                           | 115                   | 390              | 84"×19"        | 50,500                           | 47,500                 |
| 7'-0"        | 6'-0"  | 27,000                         | 200                                | 270                                 | 135                  | 150 H.p.                  | 20.0                           | 115                   | 390              | 84"×19"        | 53,000                           | 49,500                 |
| 8'-0"        | 5'-0"  | 30,000                         | 225                                | 300                                 | 150                  | 175 H.p.                  | 18.0                           | 108                   | 295              | 84"×21"        | 62,500                           | 61,000                 |
| 8'-0"        | 6'-0"  | 36,000                         | 270                                | 360                                 | 180                  | 200 H.p.                  | 18.0                           | 108                   | 295              | 84"×21"        | 65,500                           | 63,500                 |

\* Includes liners, shell, heads, bearings, countershaft and pulley, etc., but without balls

† Includes liners, shell, head, bearings, countershaft, etc., but without motor or balls.

FIG. 100.—Abbé ball mill. <sup>55</sup>

point in the spiral and is sifted by the screening. The oversize is automatically returned by the conveyor as shown in Fig. 101. The screened undersize follows the course of a second spiral underneath the screening, and is discharged from the center.

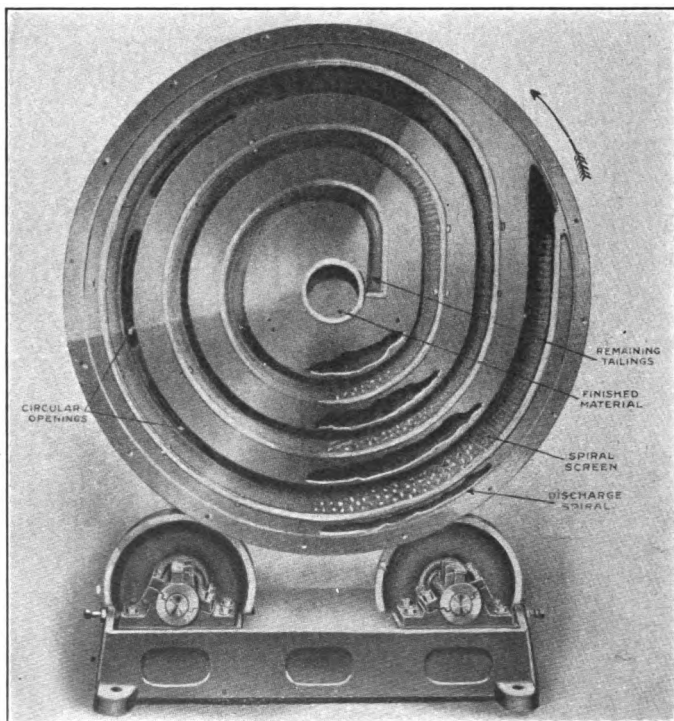


FIG. 101.—Abbé ball-mill discharge screen.<sup>55</sup>

In the **Eccleston Peripheral Discharge** for ball mills (Fig. 102) screening is accomplished by means of grizzly-type liners which are adjustable, as regards spacing, throughout the length of the mill. In the type illustrated the interior of the mill is smooth, so that grinding action would result mainly from the abrasion of the sliding balls in contact with the ore.



**Preliminary Load of Balls in a Ball Mill** may be arranged to correspond with normal sizes found under ordinary operating conditions, but tests have shown that this is not always necessary and that the balls soon wear, so that a mixture of all sizes is produced. In starting up a 5-ft. Krupp mill it is customary to make up the load as follows:

45 per cent. by weight of large balls weighing about 18 lb.

20 per cent. by weight of medium balls weighing about 9 lb.

35 per cent. by weight of small balls weighing about 5 lb.

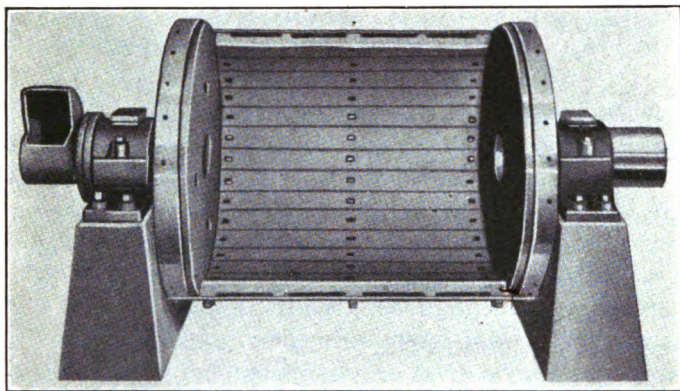


FIG. 102.—Peripheral-discharge ball mill.<sup>56</sup>

Sizes and weights of forged-steel balls in such mills are given in Table L. A special small cast-steel ball of  $\frac{7}{8}$  in.,  $1\frac{1}{2}$  in., or 2 in. diameter is made by the Allis-Chalmers Co., and weighs 5 per cent. less than a hammered-steel ball of corresponding size.

**Size of Feed in Ball Milling** should be in direct ratio to the diameter of the mill and the size of the balls used for grinding. In some instances a feed up to 6 in. in diameter has been effective where it has been found that fracture of the smaller rock was accomplished by the larger portions of the feed, but this is generally only feasible with a friable ore and a large mill. A uniform feed of 2-in. material, or thereabouts, usually gives best results with an average-size (5-ft. diam.) mill.

TABLE L.—SIZES AND WEIGHTS OF FORGED-STEEL BALLS<sup>1</sup>

| Diameter of balls,<br>in. | Weight of<br>one ball,<br>lb. | Approx.<br>number of<br>balls in<br>2000 lb. | Diameter of<br>balls, in. | Weight of<br>one ball,<br>lb. | Approx.<br>number of<br>balls in<br>2000 lb. |
|---------------------------|-------------------------------|----------------------------------------------|---------------------------|-------------------------------|----------------------------------------------|
| $\frac{7}{8}$             | 0.10                          | 20,250                                       | 3                         | 3.96                          | 505                                          |
| 1                         | 0.15                          | 13,480                                       | $3\frac{1}{2}$            | 6.34                          | 315                                          |
| $1\frac{1}{4}$            | 0.29                          | 6,230                                        | 4                         | 9.48                          | 211                                          |
| $1\frac{1}{2}$            | 0.50                          | 4,010                                        | $4\frac{1}{2}$            | 13.50                         | 148                                          |
| $1\frac{3}{4}$            | 0.79                          | 2,520                                        | 5                         | 18.54                         | 108                                          |
| 2                         | 1.18                          | 1,690                                        | $5\frac{1}{2}$            | 24.65                         | 81                                           |
| $2\frac{1}{2}$            | 2.31                          | 860                                          | 6                         | 32.00                         | 63                                           |

**Low Feed Tonnage**, in an attempt to make the mill do the work in a single passage, results in the grinding of a considerable proportion of the material beyond the required limit. In the case where all-sliming is being practised it results in a decreased duty, on account of the formation of slime in the first half of the mill as a result of an almost immediate reduction of the finer material present in the feed. A further disadvantage and loss from insufficient feed is seen in high ball consumption and excessive wear of the liners at the discharge end of the mill. This objection does not apply to the conical mill, where little effective grinding is performed at the discharge end and where wear of liners is proportionally light. **Ball-Mill Feed** should be increased to a point showing maximum grinding with minimum ball and liner consumption. Ample feed insures high duty, because, under such conditions, there is always a layer of sand between the balls, even at the discharge end. It prevents excessive ball and liner wear by cushioning the blow between ball and ball, and ball and liner, with a layer of material to be crushed. The disadvantage of high feed is seen in the necessity for a correspondingly high-duty classifying and return system; but, as elevating classifiers perform this operation at an insignificant cost, the final advantage is always in favor of an ample ball- or tube-mill feed, with a closed-circuit return system.

The **Close-Circuit System** of tube and ball milling has been shown by numerous investigations to give maximum efficiency, largely because it would be impossible to adjust any mill of this type to exactly fulfill momentary duty. Single-passage crushing to exact requirements is not practicable, because the apparatus has no flexibility and would be unable to cope with slight variations in tonnage with any prospect of efficient operation. The reason for improved output with closed-circuit grinding is due to the fact that provision is made for the removal of material already ground sufficiently fine, and at the earliest possible moment. It permits an effective visible control of operations in the quantity of classifier return, with the result that, at the outset of an accumulation in the circuit, the necessary steps can immediately be taken (by increasing pebble load or altering moisture conditions in the mill feed) to increase the grinding without stopping the feed or permitting any material alteration in the composition of the final product from the classifiers. The **grates** in certain types of ball mills were originally constructed with the idea of screening the pulp; but it is now becoming realized that if any ore particles have reached the discharge end of the mill without being ground to the required size nothing will be gained by retaining them there, where no provision exists to crush or grind more than the normal flow. Grates, when used, are now provided with larger openings, which permit the passage of partly-ground ore; and more reliance is placed on the efficient operation of a mechanical classifier to separate the finished from the unfinished product, and to return the latter to the feed end of the mill. If the grate were used as a screen, and if any particles of ore in the pulp were insufficiently ground when the screen were reached, there would be an immediate accumulation, which would interfere with the operation of the mill. The work of grinding increases as reduction in particle size proceeds, so that the smaller duty in the primary stages of grinding in a cylindrical mill is counter-balanced by the provision of an ample pulp return to the feed end.

**Comparisons Between the Work of Crushing in Wet or Dry Ball Mills** show increased duty with the use of water. At the

same time wet crushing involves shorter life for liners and increased consumption of steel balls. In summing up it may be said that the advantages are in favor of wet crushing, where possible, because first cost is practically the same for either type of mill, so that depreciation and capital charges on wet crushers are less per ton crushed than in the case of the dry type. Power is also practically the same whether the mill is crushing wet or dry, and this fact also influences the comparison in favor of wet crushing.

## SECTION X

### GRINDING IN CHILEAN, HUNTINGTON, AND SIMILAR TYPES OF MILLS

The **Chilean Mill** (Fig. 103) consists of a shallow circular trough of a diameter which denotes the size of the mill. Large-

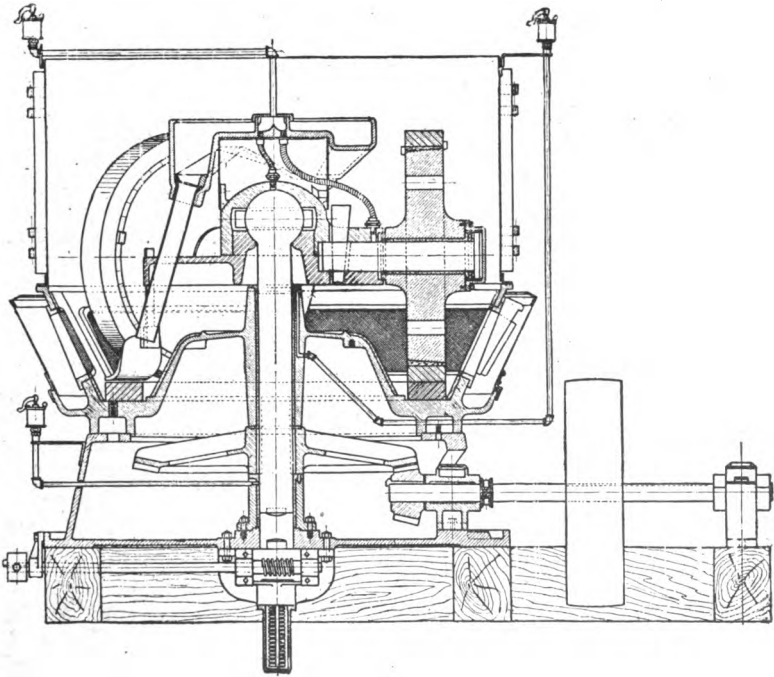


FIG. 103.—Chilean mill.<sup>18</sup>

diameter rollers of comparatively narrow face are revolved in the trough, and the ground product is discharged through

appropriate screening. Details of construction will be found in Table LI, and operation in Table LII.

The **Lane Mill** is an improved Chilean mill operating at a slow speed with an overflow discharge generally without screening. A bed of ore is kept between tires and die, and the mill is surmounted with a weight tank, which, when filled with rock or other heavy material, adds to the crushing power of the tires. Comminution is insured by a combination crushing, grinding, and abrasive action. Construction details are given in Table LIII, general operating data in Table LIV, and screen analyses in Table LV.

TABLE LI.—CHILEAN-MILL DATA<sup>18</sup>

| Size | Weight of heaviest piece | Horsepower | Speed of mill r. p. m. | Total weight |
|------|--------------------------|------------|------------------------|--------------|
| 5'   | 8,000 lb.                | 30         | 35                     | 38,000 lb.   |
| 6'   | 11,000 lb.               | 40         | 30                     | 50,000 lb.   |
| 8'   | 45,000 lb.               | 60         | 20                     | 125,000 lb.  |

TABLE LII.—CHILEAN-MILL PERFORMANCE<sup>57</sup>

|                             |                                    |
|-----------------------------|------------------------------------|
| Ore.....                    | Quartz-porphyry                    |
| Screen.....                 | 1½ mm. round hole punched          |
| Die weight.....             | 1722 each when new, total 2526 lb. |
| Tons feed per 24 hours ..   | 237                                |
| Per cent. solids in feed .. | 24.9                               |
| Ratio solids to water....   | 1 to 3                             |
| Tons dry feed per H.p.      |                                    |
| day.....                    | 6.485                              |
| H.p. per hr.....            | 36.70                              |
| Wear per ton crushed:       |                                    |
| dies.....                   | 0.11533 lb.                        |
| tires.....                  | 0.29153 lb.                        |

TABLE LII.—(Continued)

| Screening analysis |              |              |                      |                         |
|--------------------|--------------|--------------|----------------------|-------------------------|
| Mesh               | Opening, in. | Opening, mm. | Percentage by weight |                         |
|                    |              |              | Feed,<br>Per cent.   | Discharge,<br>Per cent. |
| +4                 | 0.185        | 4.699        | 0.94                 | .....                   |
| +6                 | 0.131        | 3.327        | 7.71                 | .....                   |
| +8                 | 0.093        | 2.362        | 16.49                | 0.05                    |
| +10                | 0.065        | 1.651        | 11.84                | 0.10                    |
| +14                | 0.046        | 1.168        | 8.98                 | 1.07                    |
| +20                | 0.0328       | 0.833        | 7.18                 | 3.63                    |
| +28                | 0.0232       | 0.589        | 7.43                 | 7.75                    |
| +35                | 0.0164       | 0.417        | 6.04                 | 9.08                    |
| +48                | 0.0116       | 0.295        | 4.80                 | 9.38                    |
| +65                | 0.0082       | 0.208        | 3.89                 | 8.53                    |
| +100               | 0.0058       | 0.147        | 3.76                 | 8.95                    |
| +150               | 0.0041       | 0.104        | 2.58                 | 6.23                    |
| +200               | 0.0029       | 0.074        | 1.82                 | 4.21                    |
| -200               | .....        | .....        | 16.54                | 41.02                   |
|                    |              |              | 100.00               | 100.00                  |

TABLE LIII.—LANE-MILL CONSTRUCTION DETAILS<sup>58</sup>

| Size of mill                                             | 7 ft.                | 10 ft.          |
|----------------------------------------------------------|----------------------|-----------------|
| Capacity, tons per 24 hours.....                         | 20-30                | 40-50           |
| Speed of mill, r.p.m.....                                | 11                   | 8               |
| Speed of pulleys, r.p.m.....                             | 290                  | 260             |
| Size of pulleys.....                                     | 24" × 10"            | 24" × 12"       |
| Power required to operate.....                           | 12 h.p.              | 20 h.p.         |
| Net weight.....                                          | 17,000 lb.           | 26,450 lb.      |
| Weight of heaviest piece (i).....                        | 1,240 lb.            | 1,240 lb.       |
| Height.....                                              | 6 ft.                | 6 ft.           |
| Floor space occupied (ii).....                           | 9 ft. × 15 ft. 2 in. | 12 ft. × 18 ft. |
| Distance between feed and discharge<br>levels (iii)..... | 1 ft. 10 in.         | 2 ft. 2 in.     |
| (iv).....                                                | 6 ft. 5 in.          | 6 ft. 9 in.     |
| Proper size of feed.....                                 | 1 in.                | 1 in.           |

(i) For mule-back transport, 250 lb.

(ii) With overhead drive reduce larger dimension by 6 ft.

(iii) When discharging into pan

(iv) When discharging into overhead distributor

TABLE LIV.—LANE SLOW-SPEED CHILEAN-MILL DATA<sup>59</sup>

| Data                                  | 1            | 2     | 3     | 4    | 5     | 6      | 7    |
|---------------------------------------|--------------|-------|-------|------|-------|--------|------|
| Size of mill, in feet.....            | 7            | 10    | 10    | 7    | 7     | 10     | 10   |
| Time in actual operation              | A            | 2 yr. | 3 yr. | G    | 8 mo. | 18 mo. | K    |
| Capacity, tons in 24 hours.....       | 24           | 40    | 55    | 14   | 20    | 30     | 45   |
| Horsepower required.....              | 7            | 10    | 12    | ?    | 7     | 10     | 8    |
| Gallons of water used per minute..... | M            | B     | D     | ?    | 7     | 15     | few  |
| Height of discharge, ins.             | 4            | 4     | 7     | ?    | 6     | 7      | 7½   |
| Mesh of screen, if any...             | 30           | 8     | ..    | ..   | ..    | ..     | ..   |
| Character of ore.....                 | med.         | hard  | soft  | hard | ?     | hard   | med. |
| Mesh of discharged pulp.              | 44           | 40    | E     | H    | I     | J      | L    |
| Time shut down for repairs.....       | 5 dy. p. mo. | C     | 2 hr. | ?    | ..    | ..     | ..   |
| Cost of repairs, per ton..            | 5c.          | 5c.   | F     | ?    | 3c.   | 5c.    | 4c.  |
| Size of feed, inches.....             | ½            | 1     | ½     | ½    | ½     | 1      | 1    |

## REMARKS

A—Total crushed in 8500 tons.

B—Same as a 10-stamp mill.

C—Repairs made while cleaning up.

D—Have an unlimited supply of water. No record kept of consumption.

E—90 per cent. is minus mesh.

F—Lower than stamps.

G—90 shifts to date.

H—80 per cent. is minus 100 mesh.

I—95 per cent. is minus 100 mesh.

J—68 per cent. is minus 100 mesh.

K—Milled a total of 7000 tons to date of writing.

L—73 per cent. is minus 100 mesh.

M—16,000 gal., per 24 hours.

Where not otherwise stated, no screens were used.

1. In Arizona. Considers Lane better than stamps. Feed direct from crusher to Lane mill.

2. In southern Nevada. An excellent fine grinder and amalgamator.

3. In Idaho. An ideal amalgamator; 81 per cent. caught in the mill itself.

4. In California. Not satisfied. Grinds too fine. Capacity limited.

5. In Idaho. Better than stamps as a crusher; less wear and less water needed.

6. In Nevada. Ore extremely hard; free milling; 80 per cent. of pulp through 60 mesh.

7. In Texas. An excellent machine for fine grinding.

The above data were obtained in August, 1912, from correspondence with companies actually operating the mill.



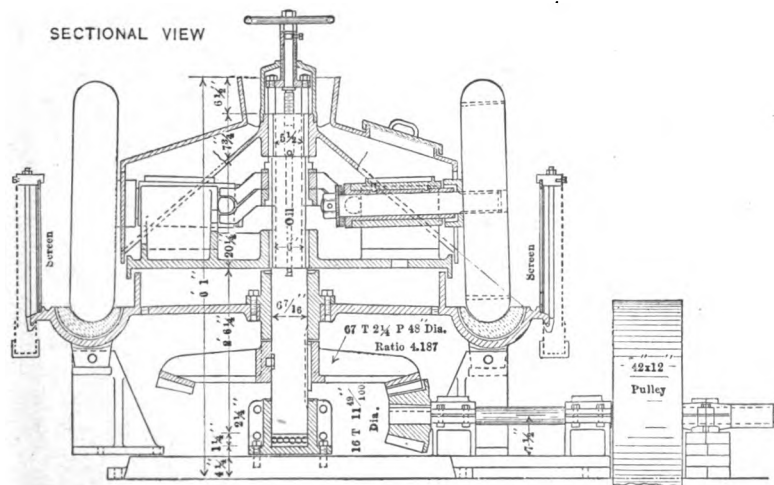
TABLE LV.—LANE-MILL SCREENING-DISCHARGE ANALYSIS<sup>60</sup>

|                                          |         |         |            |
|------------------------------------------|---------|---------|------------|
| Height of overflow discharge .....       | 8 in.   | 9½ in.  | 6 in.      |
| Screening used .....                     | 12-mesh | 12-mesh | ¼-in. mesh |
| Percentage of solution in ore pulp ..... | 68.6    | 84.8    | 82.0       |
| R.p.m. of mill .....                     | 7½      | 7½      | 8          |

## Screening Analysis

|      | Per cent. | Per cent. | Per cent. |
|------|-----------|-----------|-----------|
| +65  | 30.9      | 11.9      | 35.6      |
| +100 | 15.12     | 16.2      | 9.5       |
| +200 | 19.9      | 25.6      | 13.2      |
| -200 | 34.08     | 46.3      | 41.7      |
|      | 100.00    | 100.00    | 100.00    |

The Operation of High- and Low-Speed Chilean Mills is given in Table LVI.

FIG. 104.—Denver quartz mill.<sup>61</sup>



The **Denver Quartz Mill** (Fig. 104) consists of four rollers with convex edges running in a concave die. A scouring action is claimed, which favors the subsequent amalgamation of gold. The mills are built in three standard sizes, viz.: 3 ft. 6 in., 5 ft. 6 in., and 8 ft. in diameter. The muller rings and mortar liners are made of steel or hard iron.

The **Huntington Mill** consists of a circular pan with a central

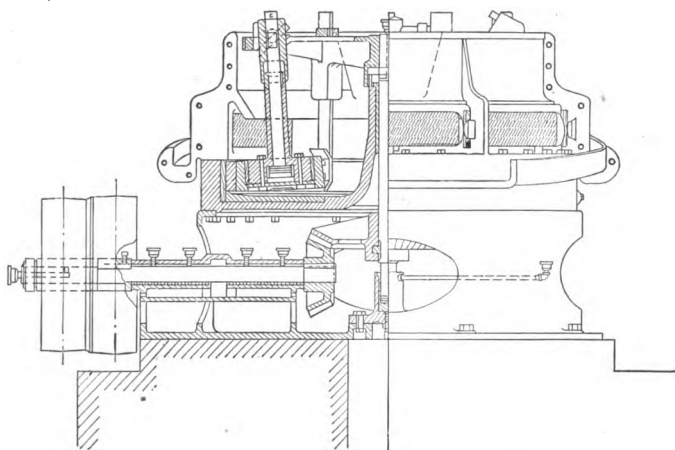


FIG. 105.—Huntington mill with iron base.<sup>8</sup>

spindle from which are suspended four arms carrying rollers. These rollers operate centrifugally and crush the material against a ring die. A screen is arranged just above the level of the rollers. This type of mill has a limited application, on account of the necessity for a smaller feed than is required by many other secondary crushers, but has been used largely as an amalgamator and crusher on small properties. A diagram of this type of mill will be found in Fig. 105 and details of operation in Table LVII.

TABLE LVII.—HUNTINGTON-MILL DATA<sup>8</sup>

| Size, ft. | Total weight, lb. | Weight of heaviest piece, lb. | Pulleys, inches | H.p. |
|-----------|-------------------|-------------------------------|-----------------|------|
| 3½        | 6,700             | 1,600                         | 24 × 5½         | 5    |
| 3½ Sect.  | 6,900             | 300                           | 24 × 5½         | 5    |
| 5         | 16,300            | 5,500                         | 30 × 8½         | 8    |
| 6         | 44,000            | 14,050                        | 48 × 12½        | 15   |

Capacity in Tons per 24 Hours and Speed of Countershaft for Different Feeds

| Size of mill, ft. | ¼-in. feed |                                   |                 | ½-in. feed |                       |          | ¾-in. feed |                      |          |
|-------------------|------------|-----------------------------------|-----------------|------------|-----------------------|----------|------------|----------------------|----------|
|                   | R.p.m.     | Capacity                          | Mesh            | R.p.m.     | Capacity              | Mesh     | R.p.m.     | Capacity             | Mesh     |
| 3½                | 150        | 5 to 9<br>15 to 22<br>23 to 46    | 100<br>40<br>20 | 135        | 15 to 22<br>26 to 38  | 40<br>20 |            |                      |          |
| 5                 | 166        | 9 to 15<br>25 to 35<br>50 to 75   | 100<br>40<br>20 | 150        | 25 to 35<br>42 to 62  | 40<br>20 | 134        | 20 to 28<br>35 to 50 | 40<br>20 |
| 6                 | 216        | 17 to 28<br>47 to 65<br>92 to 140 | 100<br>40<br>20 | 195        | 47 to 65<br>78 to 115 | 40<br>20 | 174        | 38 to 52<br>65 to 93 | 40<br>20 |

The **Griffin Mill** operates by means of a single roller attached to a vertical shaft which is thrown out by centrifugal force against a ring die. Details of the operation of 16 of these mills, since replaced by Krupp ball mills, are given in Table LVIII. The fineness of the product will be noted. The mill has found small favor among operators, on account of constant necessity for repairs and renewals.

TABLE LVIII.—GRIFFIN-MILL DATA<sup>7</sup>

|                                |                           |
|--------------------------------|---------------------------|
| Mine.....                      | Gt. Boulder Perseverance. |
| Size of mill.....              | No. 11.                   |
| Diameter of crushing roll..... | 15 in.                    |
| Diameter of ring die.....      | 30 in.                    |
| R.p.m. of shaft.....           | 198                       |
| Life of die rings.....         | 18 days                   |
| Life of roll bodies.....       | 6 months                  |
| Life of roll tires.....        | 9 days                    |
| Size of feed.....              | To pass 1¼-in. ring       |
| H.p. consumption.....          | 18                        |
| Output.....                    | 37 tons per day           |
| Screening .....                | 14 × 14 × 22 I. S. W. G.  |

## Screening analysis

| Mesh        | With 14-mesh screen<br>of 22 I. S. W. G.,<br>per cent. | With 10-mesh screen<br>of 21 I. S. W. G.,<br>per cent. | With 10-mesh screen<br>of 20 I. S. W. G.,<br>per cent. |
|-------------|--------------------------------------------------------|--------------------------------------------------------|--------------------------------------------------------|
| + 20        | 0.30                                                   | 3.50                                                   | 2.50                                                   |
| - 20 + 30   | 1.00                                                   | 5.15                                                   | 4.00                                                   |
| - 30 + 40   | 2.20                                                   | 4.75                                                   | 4.50                                                   |
| - 40 + 60   | 5.50                                                   | 8.75                                                   | 7.15                                                   |
| - 60 + 80   | 5.35                                                   | 5.25                                                   | 5.35                                                   |
| - 80 + 100  | 4.15                                                   | 4.00                                                   | 4.85                                                   |
| - 100 + 120 | 2.00                                                   | 2.65                                                   | 2.25                                                   |
| - 120 + 150 | 7.35                                                   | 5.00                                                   | 6.00                                                   |
| - 150 + 200 | 4.05                                                   | 2.15                                                   | 1.65                                                   |
| - 200       | 68.10                                                  | 58.80                                                  | 61.75                                                  |
|             | 100.00                                                 | 100.00                                                 | 100.00                                                 |

The **Sturtevant Ring Roll Mill** (Fig. 106) takes a feed up to 1½ in. In the operation of this type of mill the ring is revolved and the rolls are held against the ring by pressure. The product from the mill may be screened and the oversize returned for further reduction (see Fig. 107).

The **Marathon Mill** (Fig. 108) consists of a grinding drum, mounted on a cradle in such a way that fall between feed and discharge levels may be adjusted to suit requirements. The

grinding media consist of loose steel bars of a longitudinal dimension equal to the length of the mill. The shell is lined with steel plate having corrugations which tend to produce a wave

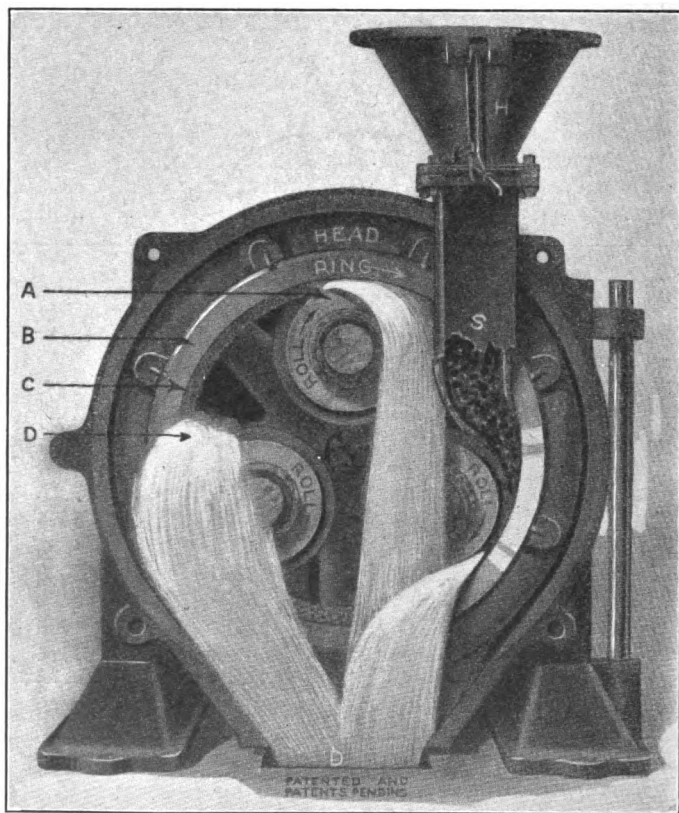


FIG. 106.—Sturtevant ring-roll mill.<sup>32</sup>

Feed enters hopper at *H*.

Spout *S* delivers it at centre of concave revolving ring where it is strongly held by centrifugal force until crushed off by the rolls, discharging at *D*.

*A* Spring-pressed rolls driven by centrifugally-held material.

*B* Rigid revolving ring drives all three rolls on 1" layer of centrifugally-held material.

*C* Thick layer of centrifugally-held, unground rock.

*D* Ground rock crushed on both sides of ring.

motion among the rods during the revolution of the mill. The mill is driven by spur gearing which is arranged centrally and

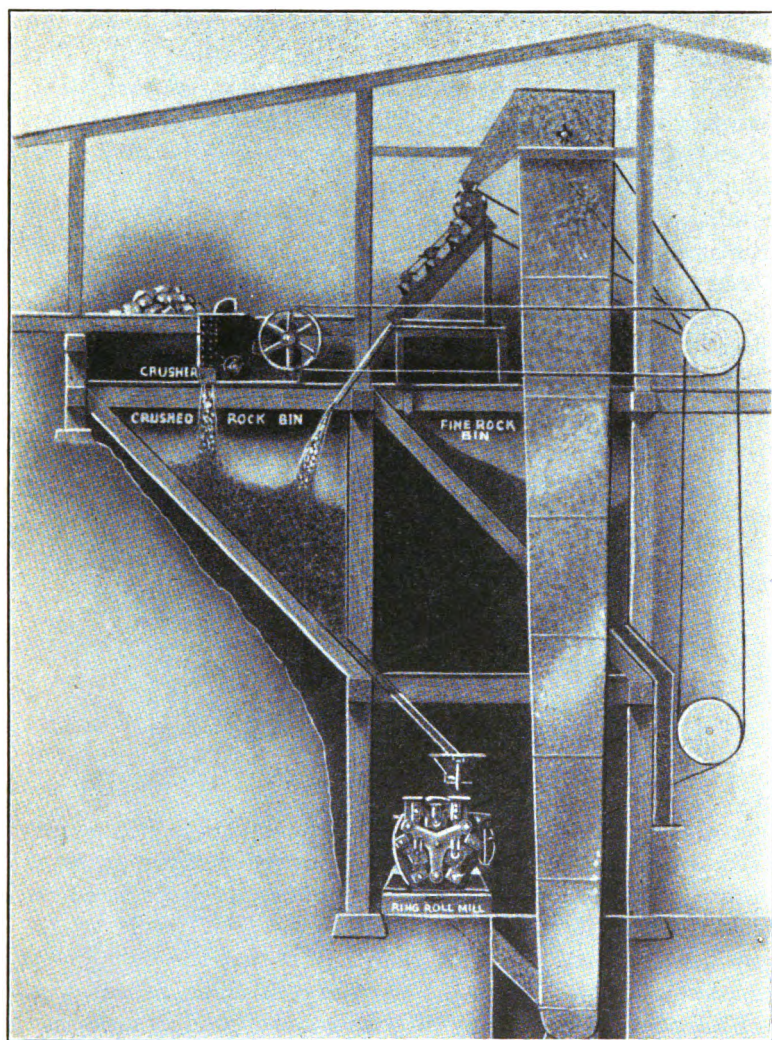


FIG. 107.—Ring-roll grinding with return system.<sup>32</sup>

between two tire rings that rest on four roller-ring bearings. An important feature of the operation of the Marathon mill is that the rods space themselves at definite distances from each other, according to the size of the particles in the feed and the product, the spacing decreasing toward the discharge end of the mill. The action is, therefore, somewhat similar to that occurring in roll crushing, small particles of ore being able to pass through the entire mill without further and possibly uneconomic reduction in size. The efficiency of the mill is, therefore, high—the momentum of each rod (and consequently its effectiveness) is distributed over the entire length. This is in distinct contrast to

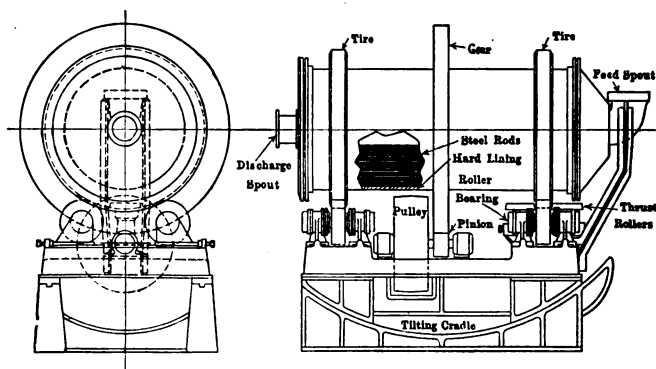


FIG. 108.—Marathon mill.<sup>42</sup>

the action in an ordinary ball mill, where impact is, necessarily, concentrated in one spot, and where low efficiency may result because of unproductive blows—unproductive either from the mechanical or economic point of view. The result of the distributed impact in a Marathon mill is that the discharge is remarkably even. When the various controlling factors have been adjusted, in conformity with the grade of product necessary, the results are often noteworthy. Other than under abnormal conditions, little or no undersize and practically no oversize escapes. The general characteristics of the discharge will alter proportionately as the feed is forced, but the evenness of the



TABLE LIX.—MARATHON-MILL PERFORMANCE <sup>57</sup>

|                                         | Test No. 1                       | Test No. 2  |
|-----------------------------------------|----------------------------------|-------------|
| Ore.....                                | Quartz monzonite porphyry        |             |
| Size of mill.....                       | 3 ft. by 7 ft.                   |             |
| Iron rod size.....                      | $\frac{1}{2}$ in. to 2 in. diam. |             |
| Charge of rods.....                     | 7000 lb.                         |             |
| Motor used.....                         | 25 h.p.                          |             |
| Speed.....                              | 30 r.p.m.                        |             |
| Ratio solids to water.....              | 1 to 1.8                         | 1 to 0.57   |
| Horsepower per hour.....                | 18.60                            | 22.50       |
| Dry feed per horsepower hour, tons..... | 0.5316                           | 0.8184      |
| Tons dry feed per 24 hr.....            | 236.5                            | 440.0       |
| Wear of liners per ton ground.....      | 0.2313 lb.                       | 0.14149 lb. |
| Wear of rods per ton ground.....        | 0.63697 lb.                      | 0.39295 lb. |

## Screening Analysis

| Mesh  | Opening,<br>in. | Opening,<br>mm. | Test No. 1         |                         | Test No. 2         |                         |
|-------|-----------------|-----------------|--------------------|-------------------------|--------------------|-------------------------|
|       |                 |                 | Feed,<br>per cent. | Discharge,<br>per cent. | Feed,<br>per cent. | Discharge,<br>per cent. |
| + 4   | 0.185           | 4.699           | 0.13               | ....                    | 0.09               | .....                   |
| + 6   | 0.131           | 3.327           | 6.49               | ....                    | 9.37               | 0.04                    |
| + 8   | 0.093           | 2.362           | 17.12              | 0.01                    | 21.58              | 0.81                    |
| + 10  | 0.065           | 1.651           | 13.40              | 0.28                    | 15.90              | 4.90                    |
| + 14  | 0.046           | 1.168           | 10.44              | 2.12                    | 13.55              | 12.05                   |
| + 20  | 0.0328          | 0.833           | 8.51               | 7.06                    | 11.14              | 15.55                   |
| + 28  | 0.0232          | 0.589           | 8.35               | 14.77                   | 10.42              | 16.82                   |
| + 35  | 0.0164          | 0.417           | 6.61               | 14.43                   | 6.96               | 12.50                   |
| + 48  | 0.0116          | 0.295           | 5.30               | 11.68                   | 3.92               | 8.53                    |
| + 65  | 0.0082          | 0.208           | 3.91               | 8.72                    | 1.97               | 5.43                    |
| + 100 | 0.0058          | 0.147           | 3.78               | 8.05                    | 1.15               | 4.67                    |
| + 150 | 0.0041          | 0.104           | 2.46               | 5.15                    | 0.66               | 2.82                    |
| + 200 | 0.0029          | 0.074           | 1.29               | 2.67                    | 0.37               | 1.70                    |
| - 200 | .....           | .....           | 12.21              | 25.06                   | 2.92               | 14.18                   |
|       |                 |                 | 100.00             | 100.00                  | 100.00             | 100.00                  |

product will remain a distinguishing feature of the result. The wear on rods is not abnormal, but they must be replaced when worn to a certain size; and this detracts, to a small extent,

from the net efficiency of results. The principle underlying the action of the mill is sound.

**Details of Results of Marathon-Mill Operation** are given in Table LIX and refer to tests made with this type of mill in competition with Hardinge pebble and Chilean mills. Improved results were obtained in the second test and may be traced to (a) better classification of feed and elimination of slime from same, (b) higher tonnage, and (c) reduction in feed moisture percentage. The reduced wear in rods and liners in the second test is also an indication that the previous test was made on an insufficient feed to protect these parts from self-abrasion. Manufacturer's information about these mills is given in Table LX.

TABLE LX.—MARATHON-MILL DATA <sup>42</sup>

| No. | Size             |               | Capacity in tons per hour            |                               | Horse power, about | Weight about, lb. |
|-----|------------------|---------------|--------------------------------------|-------------------------------|--------------------|-------------------|
|     | Outside diameter | Inside length | At initial grinding                  | Stage reduction or regrinding |                    |                   |
| 1   | 16 in. by        | 3 ft.         | up to $\frac{1}{2}$ or $\frac{3}{4}$ | up to 1 to $1\frac{1}{2}$     | 1                  | 2,000             |
| 2   | 16 in. by        | 4 ft.         | up to $\frac{3}{4}$ or 1             | up to $1\frac{1}{2}$ to 2     | 1                  | 2,500             |
| 3   | 22 in. by        | 6 ft.         | up to 2 or 3                         | up to 4 to 6                  | 4                  | 7,000             |
| 4   | 26 in. by        | 8 ft.         | up to 4 or 5                         | up to 8 to 10                 | 8                  | 12,000            |
| 5   | 26 in. by        | 10 ft.        | up to 5 or 6                         | up to 10 to 12                | 10                 | 13,000            |
| 6   | 36 in. by        | 8 ft.         | up to 10 or 12                       | up to 20 to 25                | 20                 | 26,000            |
| 7   | 36 in. by        | 10 ft.        | up to 12 or 15                       | up to 25 to 30                | 25                 | 32,000            |
| 8   | 48 in. by        | 8 ft.         | up to 25 or 30                       | up to 50 to 60                | 35                 | 45,000            |
| 9   | 48 in. by        | 10 ft.        | up to 35 or 40                       | up to 70 to 80                | 45                 | 55,000            |

| No. | Floor space, width, length, height, in feet |                |                | R.p.m., drum | Pulley size diam. and face, in. | Rod charge, lb. |
|-----|---------------------------------------------|----------------|----------------|--------------|---------------------------------|-----------------|
| 1   | 2                                           | $4\frac{1}{2}$ | 3              | 42           | $15 \times 5$                   | 850             |
| 2   | 2                                           | $5\frac{1}{2}$ | 3              | 42           | $15 \times 5$                   | 1,110           |
| 3   | $2\frac{1}{2}$                              | $7\frac{1}{2}$ | $4\frac{1}{2}$ | 38           | $24 \times 6$                   | 2,160           |
| 4   | 4                                           | 11             | 7              | 35           | $24 \times 10$                  | 3,500           |
| 5   | 4                                           | 13             | 7              | 35           | $24 \times 10$                  | 4,000           |
| 6   | $5\frac{1}{2}$                              | 11             | 9              | 30           | $29 \times 11$                  | 7,000           |
| 7   | $5\frac{1}{2}$                              | 13             | 9              | 30           | $29 \times 11$                  | 9,000           |
| 8   | 7                                           | 11             | 10             | 28           | $38 \times 12$                  | 14,000          |
| 9   | 7                                           | 13             | 10             | 28           | $38 \times 16$                  | 18,000          |

## SECTION XI

### ROLL CRUSHING

**Crushing Rolls** (Fig. 109) consist, fundamentally, of two parallel shafts, one of which is fixed and the other movable. These shafts carry metal cores on which are fixed the crushing shells. These latter consist of short cylinders of steel and

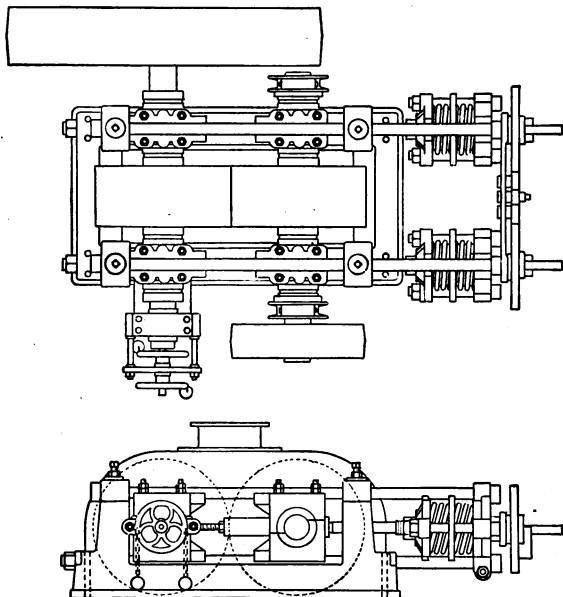
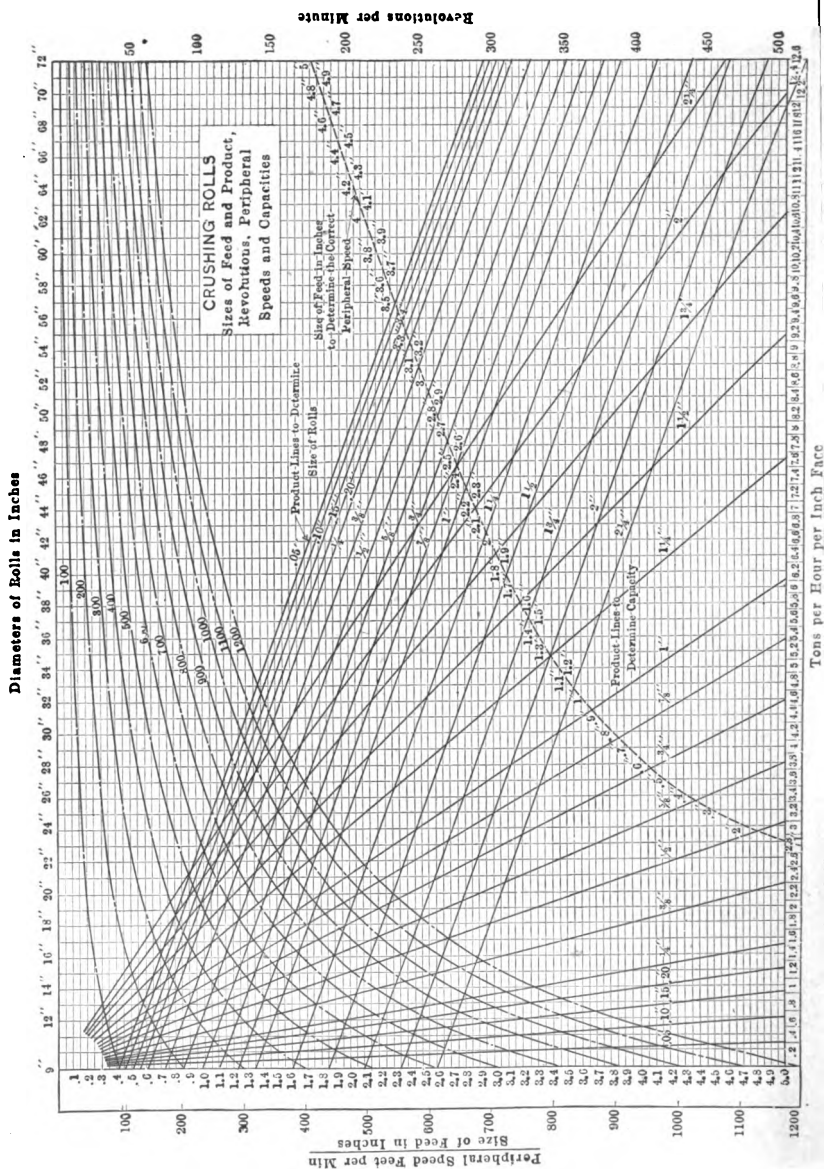


FIG. 109.—Crushing rolls.<sup>31</sup>

revolve in opposite directions, tending to lock the ore fed between them and by a pinching action crush it to a size proportionate to the dimension of the opening between roll faces. Crushing pressure is maintained by means of springs.

Fig. 110.—Crushing-roll diagram.<sup>11</sup>

The **Crushing-Roll Diagram** (Fig. 110) may be used for the determination of average roll sizes, capacities, and speeds. An illustration of the use of the diagram on the assumption that it is required to reduce 25 tons per hour of 2-in. material to  $\frac{1}{2}$  in. is given as follows:

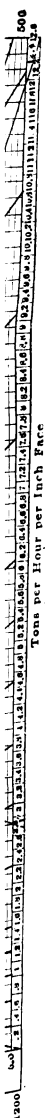
*To determine diameter of roll required:* Find the size of feed (2 in.) in the column at the left of the diagram and follow the horizontal line leading from this size to the point of intersection with the diagonal  $\frac{1}{2}$ -in. product line in the series marked "Product lines to determine size of rolls." From this point follow the nearest vertical line to the top of the diagram. The roll diameter thus found (38 in.) is the theoretical minimum diameter that can be used to reduce 2-in. feed to  $\frac{1}{2}$  in. As this is not a standard diameter, the nearest larger size of standard dimension should be used, which would be 42 in.

*To determine speed at which 42-in. rolls should run:* Find the size of feed on the curve marked "Size of feed in inches to determine correct peripheral speed," and follow the horizontal line to the left, to the column marked "Peripheral speeds, feet per minute," which will give a speed of 700 ft. per minute.

*To determine the capacity of a 42-in. roll running at 700 ft. per minute, making a  $\frac{1}{2}$ -in. product:* From the given speed (700 ft. per minute) follow the horizontal line to the right to the point of intersection with the  $\frac{1}{2}$ -in. product line in the series marked "Product lines to determine capacities." Directly underneath this point at the bottom of the table will be found a capacity given of 1.8 tons per hour per inch of face. From this we find that it will require a roll 14 in. wide to give a capacity of 25 tons per hour, but as this is not a standard width for a 42-in. roll, a 42 by 16-in. roll may be adopted.

Summing up the above we have determined that a 42 by 16-in. roll running at a speed of 700 ft. per minute will reduce 28.8 tons of 2-in. material to  $\frac{1}{2}$  in. per hour.

The above capacities are based on 25 per cent. of the theoretical tonnage of a ribbon of crushed ore of thickness equal to the distance between the roll faces, and assuming that the ore



weighs 100 lb. per cubic foot. In the above example the theoretical capacity in tons per hour

$$\begin{aligned}
 &= (60 \times 16 \times \frac{1}{2} \times 200 \times 100) \div (2000 \times 144) \\
 &= 116 \text{ tons per hour} \\
 &= 29 \text{ tons per hour at 25 per cent. efficiency.}
 \end{aligned}$$

*To find the R.p.m. of the roll at the above peripheral speed:* Follow the curve for 700 ft. per minute to the point where it intersects the vertical line under 42-in. diameter roll, and then follow the horizontal line from this point to the right of the diagram, where it will be found that this corresponds to 63 r.p.m.

**Crushing-Roll Capacities at Various Speeds** may be determined by the aid of Table LXI, giving certain factors in ratio to peripheral speed in feet per minute. The capacities resulting are 25 per cent. of the theoretical capacity and the weight of ore has been assumed to be 100 lb. per cubic foot. To find the capacity of the rolls in tons per hour, multiply the factor opposite the peripheral speed by the distance the roll faces are set apart in inches, and the result by the width of the roll face in inches.

TABLE LXI.—FACTORS FOR THE DETERMINATION OF CRUSHING-ROLL CAPACITIES AT VARIOUS SPEEDS <sup>11</sup>

| Peripheral speed, ft. per min. | Factor | Peripheral speed, ft. per min. | Factor | Peripheral speed, ft. per min. | Factor |
|--------------------------------|--------|--------------------------------|--------|--------------------------------|--------|
| 400                            | 2.08   | 675                            | 3.51   | 950                            | 4.94   |
| 425                            | 2.21   | 700                            | 3.64   | 975                            | 5.07   |
| 450                            | 2.34   | 725                            | 3.77   | 1000                           | 5.20   |
| 475                            | 2.47   | 750                            | 3.90   | 1050                           | 5.46   |
| 500                            | 2.60   | 775                            | 4.03   | 1100                           | 5.72   |
| 525                            | 2.73   | 800                            | 4.16   | 1150                           | 5.98   |
| 550                            | 2.86   | 825                            | 4.29   | 1200                           | 6.24   |
| 575                            | 2.99   | 850                            | 4.42   | 1250                           | 6.50   |
| 600                            | 3.12   | 875                            | 4.55   | 1300                           | 6.76   |
| 625                            | 3.25   | 900                            | 4.68   | 1350                           | 7.02   |
| 650                            | 3.38   | 925                            | 4.81   | 1400                           | 7.28   |

**Dry-Crushing Rolls**, although possessed of a wide range of adaptability, have an application limited to the production of material usually no finer than 10 to 15 mesh. **Wet-Crushing**

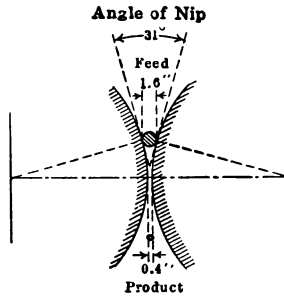


FIG. 111.—Diagram illustrating angle of nip in roll operation.<sup>16</sup>

Rolls may be operated to produce a finer product, *e.g.*, 30 mesh. Best practice in either case is indicated where a reduction of no more than four to one in diameter is achieved in one passage through each machine.

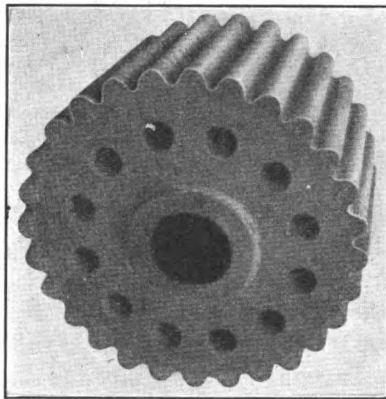


FIG. 112.—Chilled-iron corrugated roll shell.<sup>18</sup>

The **Angle of Nip** (Fig. 111) is the angle formed by tangents from the points of contact of rock and roll periphery. This angle varies with the diameter of the rolls and the distance

between the faces. The coefficient of friction is usually taken as 0.30 and the angle of nip  $31^\circ$ .

**Corrugated Roll Shells** (Fig. 112) enable a larger-sized feed to be handled in a small set of rolls than would be the case if smooth-faced shells were used.

**Even Wear of Tires** is aided by an adjustment arranged to move the stationary roll in either direction along its axis. A type of this apparatus is illustrated in Fig. 113.

**Hollow Roll Faces** are usually caused by uneven feeding.

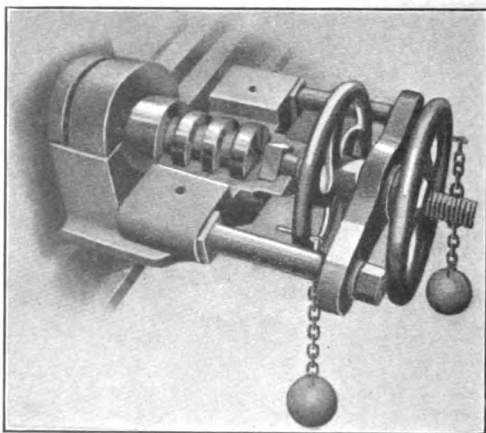


FIG. 113.—Lateral adjustment mechanism.<sup>31</sup>

This necessitates the removal of the rolls and the turning down of the faces in a lathe.

**Corrugation of Roll Faces** is largely caused by excessive size of feed beyond the dimension indicated by the angle of nip as the maximum. A second cause is found in the case where both roll faces are not traveling at identically the same speed.

**Rolls with Fleeting Action** (Fig. 114) carry an automatic lateral adjusting device whereby one roll moves across the face of the other roll twice an hour. The degree of movement depends in some measure on the size of the material being crushed. The object of this device is to prevent corrugations.



Adjustment of **Product Size** is usually made by means of gears operated by a crank. In the type illustrated (Fig. 115) parallelism of the roll faces is insured by simultaneous movement of both roll faces, and the desired adjustment is maintained by means of

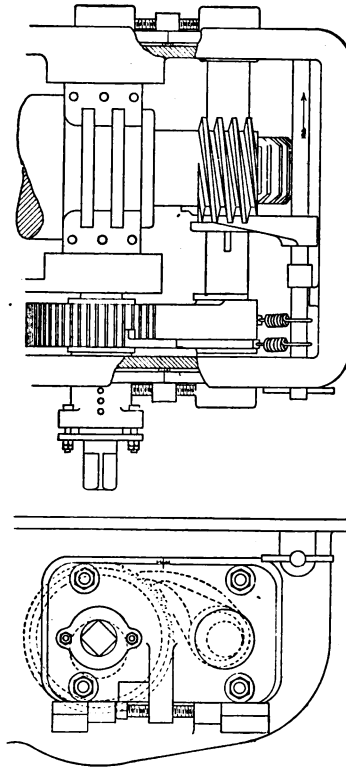


FIG. 114.—Fleeting roll mechanism.<sup>18</sup>

a key engaging the teeth of the pinion to which the shaft is attached.

**Springs in Rolls** are provided in order to prevent damage to frames and tension rods by the presence of steel or other unbreakable material in the feed.

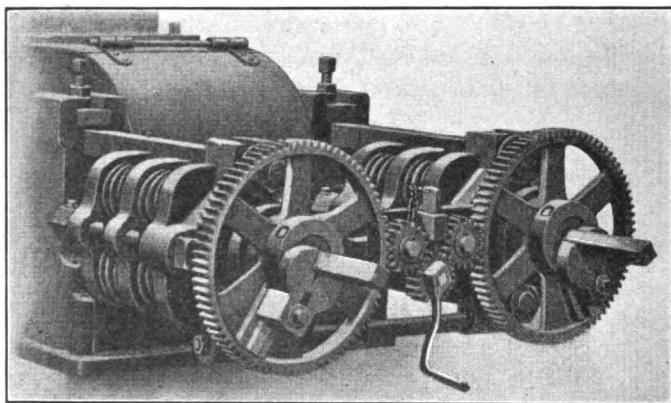


FIG. 115.—Roll adjustment gearing.<sup>31</sup>

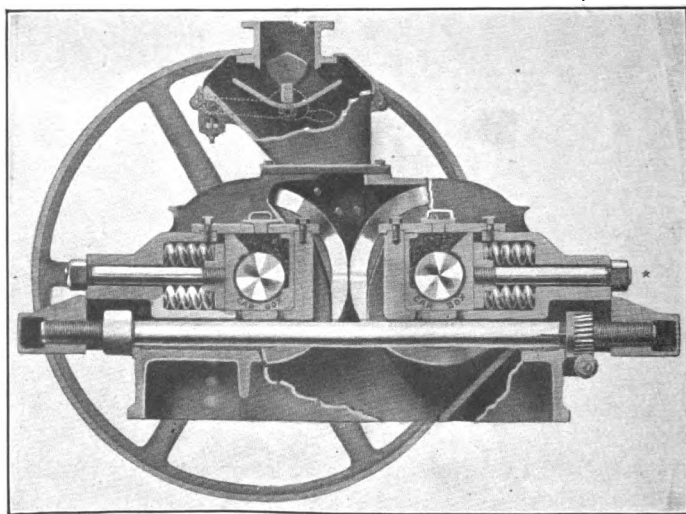


FIG. 116.—Sturtevant balanced rolls.<sup>32</sup>

**Rigid Rolls**, as their name implies, have no springs and, in consequence, operate with less vibration. They are particularly well adapted for crushing comparatively fine product where there would be less likelihood of the presence of steel of a size to do material damage.

**Balanced Rolls** (Fig. 116) are designed so that parts moving oppositely have equal weights and meet at equal speeds, and it

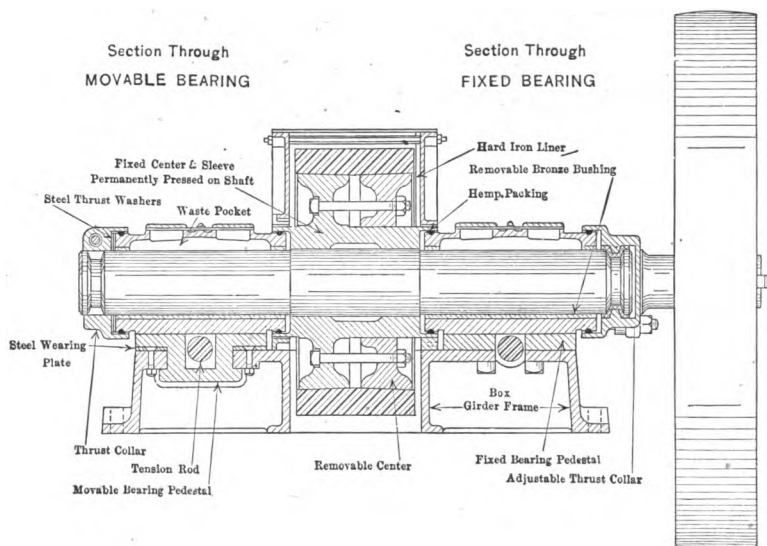


FIG. 117.—Convertible-type crushing rolls.<sup>16</sup>

is claimed that shocks are balanced, stresses minimized, and corrugations avoided to a considerable degree.

In **Convertible-Type Rolls** the rigid and spring roll parts are interchangeable. Details of construction of bearings, frame, and shaft of this type are given in Fig. 117.

**Power for Roll Crushing** is usually transmitted to a pulley fixed on a shaft extension of the fixed roll. The movable roll is generally connected with a small pulley, the function of which

is to transmit sufficient power to the roll to which it is connected to keep it revolving when not crushing.

**The High Pressure Borne by Roll Bearings** necessitates ample

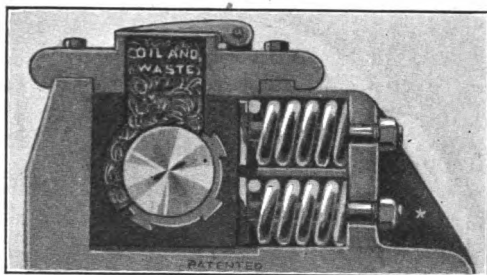


FIG. 118.—Car-box roll bearing.<sup>32</sup>

and efficient lubrication to obviate heating. Figure 118 shows a modification of the ordinary railroad-car journal method of lubrication, which has been successfully adopted for roll requirements.

## SECTION XII

### REGRINDING OR SLIMING IN PANS AND TUBE MILLS

The **Grinding Pan** (Fig. 119) consists typically of a circular cast-iron trough, usually 5 ft. in diameter, fitted with flat-faced renewable dies. These form the lower grinding surface, which is stationary. The upper grinding surface consists of renewable shoes attached to a muller plate, spider, yoke, and central shaft.

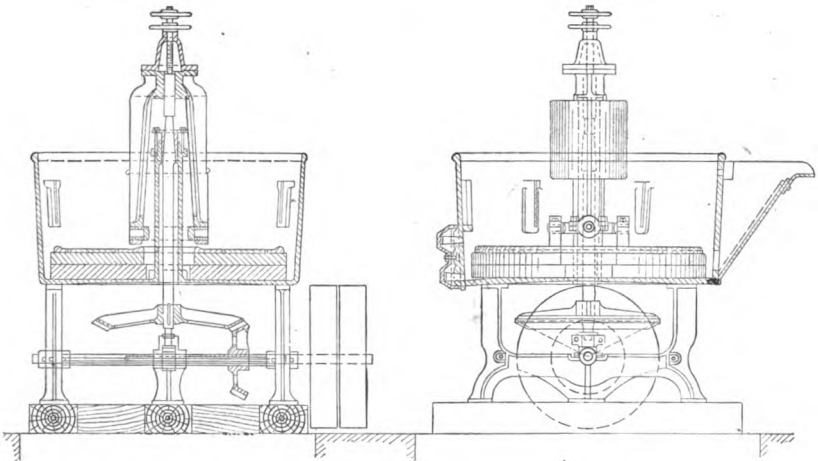


FIG. 119.—Wheeler grinding pan.<sup>7</sup>

to which power is applied through bevel gearing underneath the pan. The discharge is usually in spitzkasten form, and arranged so that any unground product overflowing is returned automatically to the pan for further reduction.

**Pan Shoes and Dies** vary in number from 8 to 18 of each per pan. They are usually  $2\frac{1}{2}$  or 3 in. thick and are made either locally at the mine from pig iron and scrap or other mixture, or

purchased in the form of hematite iron. The life of these wearing parts varies with the kind of work the pan is called upon to perform and the class of material used. Shoes locally cast from scrap usually last about a month. Better-quality material will insure a life of from 6 to 9 months.

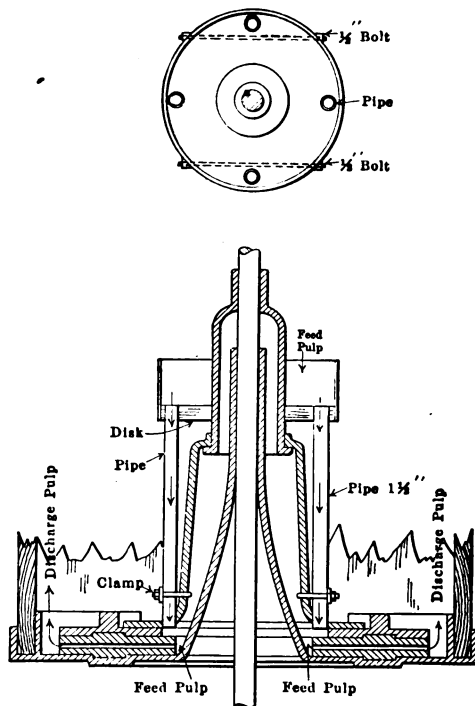


FIG. 120.—Standard amalgamating and grinding pan, with central-pipe feed.<sup>62</sup>

**Central Feed for Grinding Pans** may be arranged by a system of pipes leading from a feed-box around the top of the spider (Fig. 120) or by means of a central feed cylinder (Fig. 121). With the latter arrangement all feed must necessarily pass between shoes and dies before reaching the pulp-discharge point.

**A Classifying Pipe Discharge** may be arranged through the side of the pan (see Fig. 121). A pipe extends into the pan

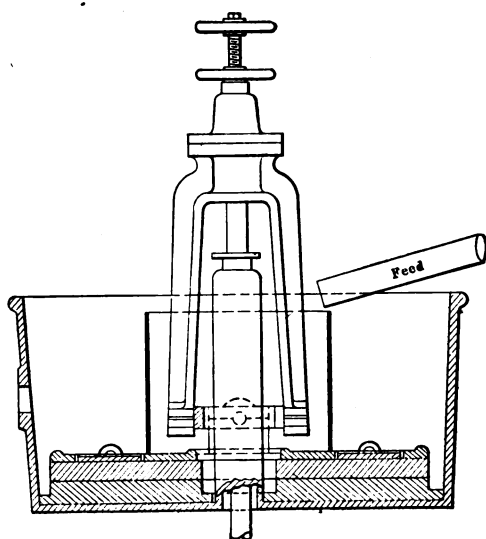


FIG. 121.—Cylinder central feed for grinding pans.

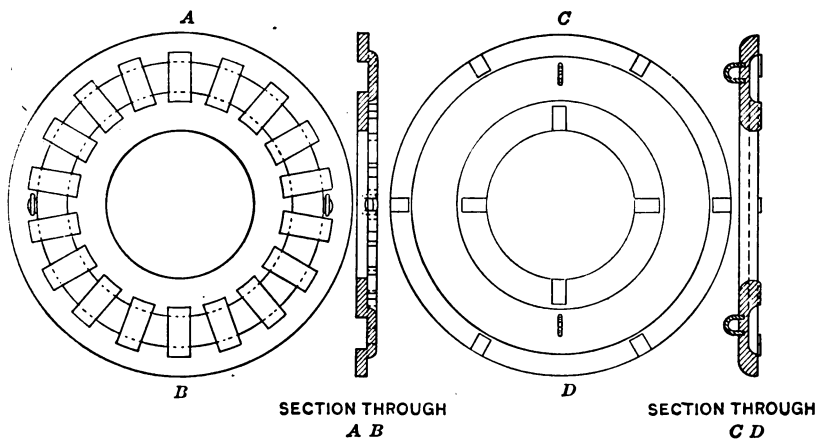


FIG. 122.—Compensating weights for grinding pan.<sup>7</sup>

and terminates about halfway toward the center in a bend or elbow. A classifying action based on centrifugal forces occurs, the coarser particles being kept toward the edge of the pan.

**Compensating Weights**, to allow for loss of weight occasioned in wear of shoes, are an important factor in the efficient working of an ordinary grinding pan. Inability to realize this fact constitutes one of the principal reasons for failure. The type of weight shown in Fig. 122 is used extensively, and was originally designed at the Ivanhoe Mine, West Australia. The ring weighs 600 lb. and is slipped on over the yoke, and rests on the muller plate. Grading analyses with pans driven at 57 r.p.m. and consuming  $6\frac{1}{2}$  h.p. are given in Table LXII.

TABLE LXII.—EFFECT OF COMPENSATING WEIGHTS IN PAN GRINDING <sup>7</sup>

| Screening | Discharge grading analysis           |                                         |                                      |                                         |
|-----------|--------------------------------------|-----------------------------------------|--------------------------------------|-----------------------------------------|
|           | 18 tons per day                      |                                         | 22 tons per day                      |                                         |
|           | With compensating weights, per cent. | Without compensating weights, per cent. | With compensating weights, per cent. | Without compensating weights, per cent. |
| + 40      | .....                                | .....                                   | 0.1                                  | 0.5                                     |
| — 40+ 60  | 0.3                                  | 3.5                                     | 1.7                                  | 16.7                                    |
| — 60+100  | 11.7                                 | 48.5                                    | 24.2                                 | 50.2                                    |
| —100+150  | 11.7                                 | 10.2                                    | 18.5                                 | 8.9                                     |
| —150      | 76.3                                 | 37.8                                    | 55.5                                 | 23.7                                    |
|           | 100.0                                | 100.0                                   | 100.0                                | 100.0                                   |

The **Advantages of Grinding Pans** for small- or medium-tonnage operations are seen in

- (i) Immediate accessibility of all parts.
- (ii) Availability as amalgamators.
- (iii) Small unit capacity, resulting in less disorganization in mill output during repair.
- (iv) Low unitary power consumption with no extra or overload provision necessary for starting up.
- (v) Wearing parts of simple shape and design and can be cast from scrap metal.
- (vi) Rapid discharge of ground material with less necessity for elimination of fines from feed than with other types of fine grinders.
- (vii) Automatic return of unground product to body of pan.



**Criticism Against Grinding Pans** has been too often based on the experience with an ancient type of apparatus known as the standard grinding and amalgamating pan (Fig. 120). In this machine the number and dimensions of both shoes and dies are inadequate, the grinding area is insufficient, and no provision exists to maintain grinding-surface weight. The principal objection against grinding pans is that they require adjustment and are not so fool-proof as tube mills.

**Grinding Pans** may be used either as **Stage Grinders** or as **Slimers**. Details of operation in both capacities are given in Tables LXIII, LXIV, and LXV.

TABLE LXIII.—OPERATION OF PANS USED FOR STAGE GRINDING<sup>7</sup>

| Mine                  | Sons of Gwalia          | L. V. Consols           | Gt. Fingall  |
|-----------------------|-------------------------|-------------------------|--------------|
| Material              | Classified sand product | Middlings from Wilfleys | Sand         |
| Condition of material | Raw                     | Raw                     | [Raw         |
| R.p.m. ....           | 45                      | 45                      | 45           |
| H.p. ....             | 5½                      | 7                       | 5            |
| Size of pan. ....     | 5 ft.                   | 5 ft.                   | 5 ft.        |
| Tons per day. ....    | 33                      | 30                      | 33           |
| Type of pan. ....     | Wheeler                 | Wheeler                 | Forwood Down |

### Screening Analysis

| Mine        | Sons of Gwalia  |                      | L. V. Consols   |                      | Gt. Fingall     |                      |
|-------------|-----------------|----------------------|-----------------|----------------------|-----------------|----------------------|
| Mesh        | Feed, per cent. | Discharge, per cent. | Feed, per cent. | Discharge, per cent. | Feed, per cent. | Discharge, per cent. |
| + 40        | 50.5            | 12.5                 | 28.34           | 4.00                 | 66.8            | 26.6                 |
| — 40 + 60   | 30.0            | 27.5                 | 9.19            | 2.5                  | .....           | .....                |
| — 60 + 80   | .....           | .....                | 21.06           | 14.75                | .....           | .....                |
| — 80 + 100  | 17.5            | 24.0                 | 6.32            | 8.52                 | .....           | .....                |
| — 100 + 120 | .....           | .....                | 9.88            | 17.80                | .....           | .....                |
| — 120 + 150 | 1.5             | 7.5                  | 2.78            | 5.65                 | 18.2            | 50.3                 |
| — 150       | 0.5             | 28.5                 | 22.43           | 46.78                | 15.0            | 23.1                 |
|             | 100.0           | 100.0                | 100.00          | 100.00               | 100.0           | 100.0                |

TABLE LXIV.—OPERATION OF PANS USED FOR FINE GRINDING<sup>7</sup>

| Mine                                   | Kalgurli             | Associated             | L. V. Consols                      |
|----------------------------------------|----------------------|------------------------|------------------------------------|
| Material                               | Sand                 | Ore                    | Concentrate                        |
| Condition                              | Roasted              | Roasted                | Roasted                            |
| Gold recovered in pans by amalgamation | 12 % of value of ore | 22 % of total recovery | 51 % of total value of concentrate |
| R.p.m. ....                            | 53                   | 47                     | 40                                 |
| H.p. ....                              | .....                | 5.2                    | 7.0                                |
| Size of pan. ....                      | 5 ft.                | 5 ft.                  | 5 ft.                              |
| Tons per day. ....                     | 8-10                 | 15                     | 30                                 |
| Type of pan. ....                      | Wheeler              | Wheeler                | Wheeler                            |

## Screening Analysis

| Mine        | Kalgurli        |                      | Associated      |                      | L. V. Consols   |                      |
|-------------|-----------------|----------------------|-----------------|----------------------|-----------------|----------------------|
| Mesh        | Feed, per cent. | Discharge, per cent. | Feed, per cent. | Discharge, per cent. | Feed, per cent. | Discharge, per cent. |
| + 40        | 18.1            | .....                | 5.99            | 0.05                 | 17.81           | .....                |
| - 40 + 60   | 21.2            | .....                | 16.45           | 0.08                 | 5.87            | 0.38                 |
| - 60 + 80   | .....           | .....                | 10.90           | 0.28                 | 19.52           | 3.97                 |
| - 80 + 100  | 42.2            | .....                | 7.63            | 0.89                 | 5.55            | 4.35                 |
| - 100 + 120 | 6.1             | 1.16                 | 4.31            | 1.63                 | 9.07            | 9.30                 |
| - 120 + 150 | 6.1             | 5.89                 | 4.95            | 2.51                 | 4.77            | 5.60                 |
| - 150       | 6.3             | 92.95                | 49.77           | 94.56                | 37.41           | 76.40                |
|             | 100.0           | 100.00               | 100.00          | 100.00               | 100.00          | 100.00               |

**Wheeler-Type Grinding Pans** were previously in use at the Homestake. These were 5 ft. in diameter, consumed 8.4 h.p. at 58 r.p.m. and handled just under 20 tons per day per pan. Grading analyses of feed and discharge will be found in Table LXVI.

**Grinding-Pan Practice with Closed Circuit and Dorr Classification** is in operation in Bolivia, and, according to Söhnlein, a pan, with a central feed of 38 tons per day, running at 60 r.p.m. with a consumption of 6.26 h.p., is capable of grinding 30 tons of sand per day to pass 200 mesh. The feed showed about 70 per cent. between 30 and 100 mesh.

TABLE LXV.—AUSTRALIAN GRINDING-PAN PRACTICE<sup>63</sup>

| Data                                               | Persuance      | South Kalgurli     | Great Boulder Prop. | Assoc. Northern |
|----------------------------------------------------|----------------|--------------------|---------------------|-----------------|
| Monthly tonnage.....                               | 19,000         | 9,030              | 18,000              | 3,700           |
| Daily tonnage.....                                 | 633            | 301                | 600                 | 123             |
| Tons on 150 mesh (requires grinding).....          | 209            | 131                | 225                 | 56              |
| Tons through 150 mesh (already ground).....        | 424            | 170                | 375                 | 67              |
| On 150, per cent.....                              | 33             | 43.6               | 37.5                | 45.5            |
| Through 150, per cent.....                         | 67             | 56.4               | 62.5                | 54.5            |
| After grinding in pans, per cent. on 150.....      | 28.4           | 12.6               | 29.0                | 12.5            |
| After grinding in pans, per cent. through 150..... | 71.6           | 87.4               | 71.0                | 87.5            |
| Number of pans.....                                | 17             | 7                  | 22                  | 8               |
| Diameter of pans.....                              | 8'             | Five 8' and Two 5' | 5'                  | 5'              |
| Revolutions per minute.....                        | 10-30 and 7-25 | 33 and 55          | 60                  | 47              |
| Total die area of pans in square feet.....         | 537            | 183                | 279                 | 101             |
| Horsepower per pan.....                            | 8.0            | 12 and 7           | 7                   | 5.1             |

In the **Cobbe Pan** the pressure between shoes and dies is maintained constant by the use of levers that are weighted in such a way as to keep the dies in adjusted pressure against the shoes. This type of pan is arranged for screen discharge, is fitted with arrangements for central feed, and is particularly well adapted for stage grinding. Details of operation are given in Table LXVII.

TABLE LXVI.—HOMESTAKE PAN GRADING ANALYSES<sup>51</sup>

|       | Feed,<br>per cent. | Discharge,<br>per cent. |
|-------|--------------------|-------------------------|
| + 50  | 38.4               | 4.0                     |
| + 80  | 42.0               | 12.5                    |
| + 100 | 9.9                | 13.5                    |
| + 200 | 6.8                | 28.0                    |
| - 200 | 2.9                | 42.0                    |
|       | 100.0              | 100.0                   |

TABLE LXVII.—COBBE GRINDING-PAN DATA

|                           |                      |
|---------------------------|----------------------|
| Screening on battery..... | 8 × 8 mesh           |
| Screening on pan.....     | 14 × 14 mesh         |
| Feed to pan.....          | 66.6 tons per 24 hr. |
| R.p.m. of pan.....        | 44                   |

Grading Analysis

| Mesh  | Feed,<br>per cent. | Discharge,<br>per cent. |
|-------|--------------------|-------------------------|
| + 20  | 17.70              | 0.03                    |
| + 40  | 16.73              | 1.43                    |
| + 60  | 9.30               | 10.93                   |
| + 80  | 7.40               | 14.43                   |
| + 100 | 5.60               | 10.17                   |
| + 120 | 1.63               | 2.17                    |
| + 150 | 3.06               | 8.27                    |
| - 150 | 38.58              | 52.57                   |
|       | 100.00             | 100.00                  |

**Tube-Milling Practice** illustrates an important adaptation in ore-reduction methods. Originally borrowed from the cement industry, and worked without modification in design, the machine has passed through many stages of improvement. The original silix lining of flint blocks has been largely replaced by hard

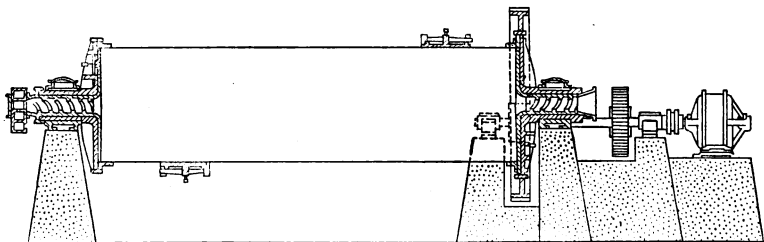


FIG. 123.—Tube mill with motor drive.<sup>18</sup>

metal lining. The expensive imported flints used as grinding media are rarely available, and manufactured pebbles of hard rock, mine rock, or small steel balls are generally used.

**Tube Mills** are usually constructed of a diameter varying between 4 and 6 ft. The length depends on practice requirements, such as fineness of grinding desired and tonnage to be handled. They are arranged to operate horizontally and without fall. Power is transmitted through suitable gearing, and the mill is usually thrown into or out of action by means of some type of friction clutch, which should be of ample capacity (usually twice the average mill load). The initial power required to start a mill of this type is high, especially where the contents have cemented to a certain extent since the previous shut-down.

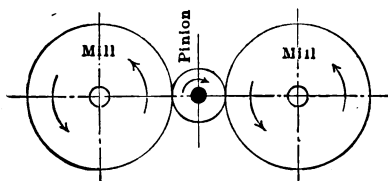


FIG. 124.—Floating tube-mill pinion.

**Power for Tube Mills** may be transmitted by belting or chain drive; or the countershaft may be motor connected by suitable flexible coupling (Fig. 123). A floating pinion (Fig. 124), with balanced thrusts, may be arranged by driving two mills,

placed parallel, from the one pinion countershaft. By arranging a wide sole plate for the trunnion bearings, fitted with adjusting screws, either mill may be thrown out of action for repair or examination by unclutching the pinion shaft, and moving the mill on the sole plates so that the spur-wheel teeth are out of range of the driving pinion.

**Tire and Roller-Bearing Tube Mills** (Fig. 125) are said to consume less power than those equipped with trunnion bearings. A combination of trunnion and tire-and-roll bearings is sometimes used. The principal advantage of tire-and-roller support is seen

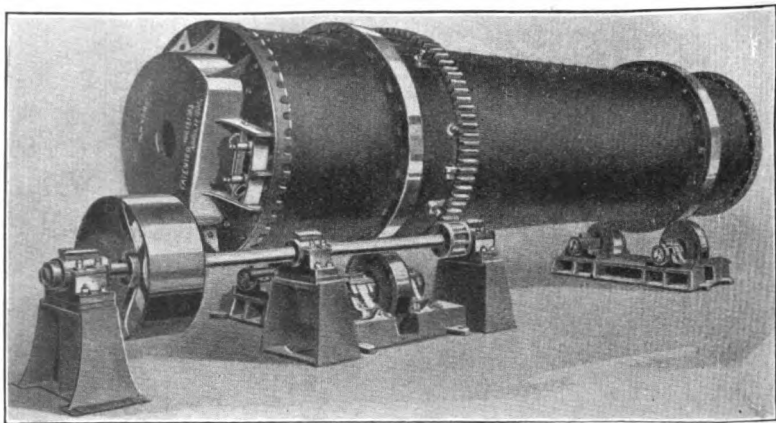


FIG. 125.—Tire and roller bearing tube mill.<sup>55</sup>

in increased diameter of discharge opening screen grizzly (Krupp type), or large diameter spiral discharge (Abbé type).

**Gear Drives for Tube Mills** are shown in Figs. 126 and 127. The spur-gear drive is usually adopted, results in lower horsepower consumption, and is an arrangement permitting greater rigidity in countershaft operation.

**Tube Mill Driving Shaft** should be as near in line with the horizontal axis of the mill as possible, so that a single sole plate may be used for trunnion and countershaft bearings, with the advantage of greater rigidity and easier adjustment. The wear of white metal used in babbitting the trunnion bearings causes a

sinking of the mill. This necessitates an adjustment of the countershaft and pinion if the latter are not placed as suggested.

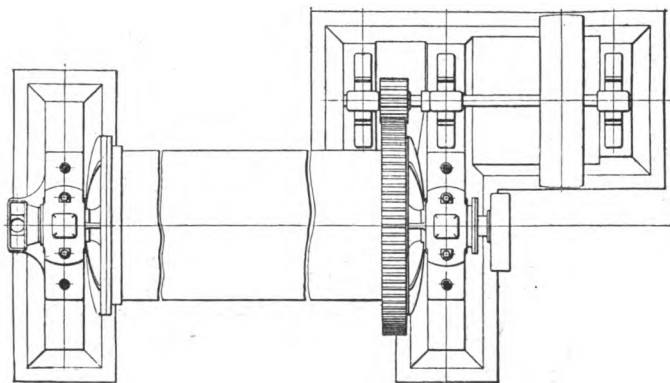


FIG. 126.—Spur gear tube-mill drive.<sup>11</sup>

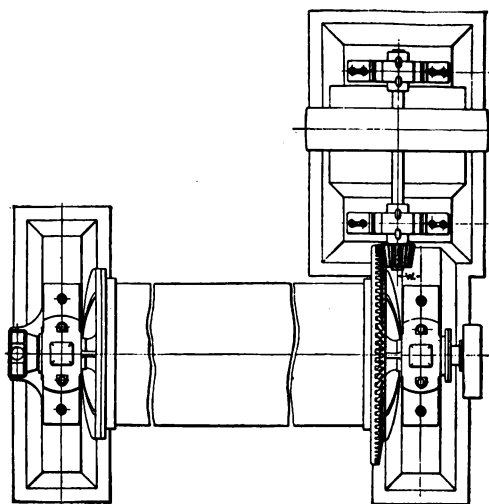


FIG. 127.—Bevel gear tube-mill drive.<sup>11</sup>

**Roller Bearings** for tube-mill trunnion bearings have been tried, and their adoption has resulted in a marked decrease in power

consumption. Conditions around a tube mill are, however, against keeping the rollers clean, with the result that they have not been adopted to any extent.

**Feeding into the Tube Mill** is usually accomplished by means of a simple form of scoop spiral, of a size in proportion to the maximum pebble diameter. The feed-end trunnion is lined with a spiral shell, which tends to carry the material into the mill (Fig. 123). The discharge end is sometimes fitted with a reverse spiral for the purpose of retaining pebbles in the mill.

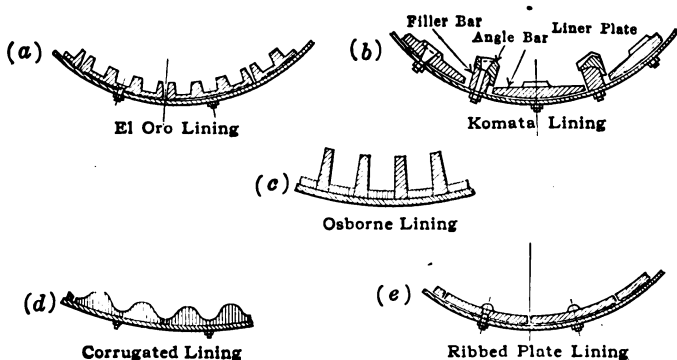


FIG. 128.—Sectional views of tube-mill linings.

**Short Tube Mills** are used where sliming is not required, and are suitable for regrinding tailings or middlings in concentrator mills, or for the reduction to a suitable mesh of a coarse battery product for subsequent leaching treatment. Details of this class of mill are given in Table LXVIII.

The **Improved Efficiency** resulting from the use of **short tube mills** is receiving increasing recognition. A statement of the results of comparative tests made with reference to the operation of cylindrical and conical mills is given in Table LXIX.

The **El Oro Tube-Mill Lining** (Fig. 128) consists of hard-metal castings carrying grooves having a slight taper inward toward



the mill circumference. These recesses extend along the length of the mill and are designed of a width to allow the pebbles used for grinding to wedge into place, thus forming a protective layer against the metal. This type of lining originated in Mexico, and has been extensively adopted elsewhere.

**Corrugated Tube-Mill Lining** (Fig. 128) insures considerable movement of the pebbles and prevents slippage and consequent low crushing efficiency. The type has been used largely with Krupp mills.

TABLE LXVIII.—DETAILS OF SHORT TUBE MILLS <sup>18</sup>

| Size                     | Weight, lb. | Weight of iron lining, lb. | H.p. | R.p.m. mill | Charge of flint pebbles, lb. |
|--------------------------|-------------|----------------------------|------|-------------|------------------------------|
| 4 feet 0 inches × 6 feet | 14,000      | 5,400                      | 10   | 32          | 3,600                        |
| 4 feet 6 inches × 6 feet | 18,000      | 6,000                      | 15   | 29          | 4,600                        |
| 5 feet 0 inches × 6 feet | 23,000      | 6,600                      | 23   | 27          | 6,000                        |
| 5 feet 6 inches × 6 feet | 30,000      | 7,200                      | 30   | 23          | 7,500                        |
| 6 feet 0 inches × 6 feet | 33,000      | 8,400                      | 37   | 21          | 9,000                        |
| 7 feet 0 inches × 6 feet | 37,000      | 9,000                      | 45   | 18          | 13,000                       |

The **Komata Tube-Mill Lining** (Fig. 128) consists of longitudinal plates, with maximum thickness where wear is greatest, and longitudinal shoes, both of hard steel. The latter serve to raise the pebbles and are the principal grinding-efficiency factor in this type of lining. Each 4-ft.-diameter mill has eight ribs, measuring 3 in. by 2½ in., and the correct speed is given as 27½ r.p.m. For the 5-ft. mill, ten ribs are required, measuring 3½ in. by 3 in., and the mill should revolve at 24 r.p.m. Calculated speed for a mill with Komata lining is considerably below the requirements for ordinary practice.

**Ribbed-Plate Tube-Mill Lining** (Fig. 128) is a simple type in which a variation in the projection of the ribs may be adopted to modify or increase the degree of lifting of the pebbles.

The **Osborne Tube-Mill Lining** (Fig. 128) consists of steel bars placed alternately lengthwise and edgewise against the inside of the mill shell. The lining is held in position by the wedging

TABLE LXIX.—DETAILS OF SHORT TUBE-MILL OPERATION

**7' × 10' Power & Mining Cylindrical Tube Mill**  
vs.

**8' × 30" Hardinge Conical Pebble Mill**

NOTE:—The object in view being to grind the largest possible amount of the material so that it will pass a 40-mesh screen and at the same time avoid producing an excess of 240-mesh material, both mills were in a closed circuit containing a hydraulic classifier and concentrating table so that the oversize of 40 mesh was returned to the tube mills.

|                                                          | P. & M.                                   | Hardinge           |
|----------------------------------------------------------|-------------------------------------------|--------------------|
| Dimensions of Mills.....                                 | 7' × 10'                                  | 8' × 30'           |
| Drives.....                                              | Individual Motors Belted to Pinion Shaft. |                    |
| Gear.....                                                | 100 Teeth                                 | 118 Teeth          |
|                                                          | 4" Pitch                                  | 2½" Pitch          |
|                                                          | 127.3" P.D.                               | 93.9" P.D.         |
|                                                          | 14" Face                                  | 6" Face            |
| Pinion.....                                              | 16 Teeth                                  | 17 Teeth           |
|                                                          | 20.4" P.D.                                | 13.5" P.D.         |
|                                                          | 14" Face                                  | 6½" Face           |
| Gear and Pinion Ratio.....                               | 6.25:1                                    | 6.94:1             |
| Feed Scoop.....                                          | 3 Cup Spiral                              | Single Cup Spiral  |
| Dimensions of Trunnion Bearings.....                     | 24" × 24"                                 | 12¾" Dia.<br>× 9½" |
| Wet tons feed per 24 hr.....                             | 485.00                                    | 218.0              |
| Average moisture in feed—per cent.....                   | 35.9                                      | 35.6               |
| Dry tons of feed per 24 hr.....                          | 310.7                                     | 139.8              |
| Ratio of feed to mills.....                              | 2.22 to 1.00                              |                    |
| Per cent. of material on 40 mesh in feed.....            | 83.1                                      | 82.9               |
| Per cent. material on 40 mesh in discharge.....          | 26.2                                      | 26.6               |
| Ratio of reduction on 40 mesh material.....              | 3.18:1                                    | 3.12:1             |
| Tons reduced through 40 mesh per 24 hr.....              | 176.7                                     | 78.8               |
| Ratio between mills.....                                 | 2.24 to 1.00                              |                    |
| Per cent. of mineral on 40 mesh in feed.....             | 77.3                                      | 80.2               |
| Per cent. of mineral on 40 mesh in discharge.....        | 18.3                                      | 20.9               |
| Ratio of reduction on 40 mesh mineral.....               | 4.23:1                                    | 3.84:1             |
| Per cent. of material on 80 mesh in feed.....            | 98.4                                      | 98.4               |
| Per cent. of material on 80 mesh in discharge.....       | 56.2                                      | 56.7               |
| Ratio of reduction on 80 mesh material.....              | 1.75:1                                    | 1.73:1             |
| Tons reduced through 80 mesh per 24 hr.....              | 131.1                                     | 58.3               |
| Ratio between mills.....                                 | 2.24 to 1.00                              |                    |
| Per cent. of mineral on 80 mesh in feed.....             | 96.8                                      | 97.0               |
| Per cent. of mineral on 80 mesh in discharge.....        | 46.2                                      | 50.4               |
| Ratio of reduction on 80 mesh mineral.....               | 2.09:1                                    | 1.92:1             |
| Per cent. of through 240 mesh material in feed.....      | 0.1                                       | 0.3                |
| Per cent. of through 240 mesh material in discharge..... | 18.0                                      | 20.4               |
| Per cent. increase in through 240 mesh material.....     | 17.9                                      | 20.1               |
| Tons through 240 mesh material produced per 24 hr.....   | 55.6                                      | 28.1               |

TABLE LXIX.—Continued

|                                                                                         | P. & M.                  | Hardinge     |
|-----------------------------------------------------------------------------------------|--------------------------|--------------|
| Ratio between mills.....                                                                | 1.98 to 1.00             |              |
| Per cent. of through 240 mesh material produced in tonnage reduced through 40 mesh..... | 31.5                     | 35.6         |
| Tons reduced through 40 mesh while producing one ton of through 240 mesh material.....  | 3.18                     | 2.80         |
| Speeds, R.P.M.....                                                                      | 22                       | 30           |
| Speeds feet per minute at large diameter.....                                           | 483                      | 753          |
| Average height of pebble load.....                                                      | Two inches above center. |              |
| Original charge of No. 4 Danish pebbles.....                                            | 20,250 lb.               | 11,200 lb.   |
| Average pebble consumption per day.....                                                 | 979 lb.                  | 521 lb.      |
| Ratio between mills.....                                                                | 1.88 to 1.00             |              |
| Pebbles consumed per ton material ground.....                                           | 3.15 lb.                 | 3.73 lb.     |
| Pebbles consumed per ton of material reduced through 40 mesh.....                       | 5.54 lb.                 | 6.61 lb.     |
| Cost of pebbles per ton of material ground.....                                         | \$0.048                  | \$0.057      |
| Cost of pebbles per ton of material ground reduced through 40 mesh.....                 | \$0.085                  | \$0.101      |
| Average power consumption E.H.P.....                                                    | 91.9                     | 64.4         |
| Power consumed per ton of material ground.....                                          | 7.10 E.H.P.              | 11.06 E.H.P. |
| Cost of power per ton of material ground.....                                           | \$0.037                  | \$0.058      |
| Power consumed per ton material reduced through 40 mesh E. H. Powers Hours.....         | 12.48                    | 19.61        |
| Cost of power per ton material reduced through 40 mesh.....                             | \$0.066                  | \$0.103      |
| Tons reduced through 40 mesh per horsepower day.....                                    | 1.92                     | 1.23         |

action, and no bolts are used. The recessed bars, which are subjected to practically no wear, and consequently do not require renewal, are usually  $2\frac{1}{2}$  in. by  $\frac{3}{4}$  in. The radial bars have a slight taper and measure 4 in. by  $1\frac{1}{4}$  in. by  $\frac{3}{4}$  in. This type of lining was designed in South Africa and has been adopted there to some extent.

**A Combination Lining of Cast-Iron Ribs and Sillex Blocks** is used at the Liberty Bell Mill, according to A. J. Weinig, and it has been found that the addition of the iron rib to every four rows of blocks has resulted in extending the life of the lining to nearly three years of continuous wear. The ribs used are tapered and measure  $1\frac{3}{4} \times 2 \times 4\frac{1}{2}$  in. and are  $47\frac{1}{2}$  in. long. The blocks are set with portland cement in sections and steamed for eight hours, the completed lining being finally steamed for 12 hours before the mill is put into commission.

TABLE LXX.—EFFECT OF PEBBLE LOAD VARIATION IN TUBE MILLING<sup>11</sup>

Size of mill, 23 ft. × 5 ft.

Tons ore per 24 hours, 172

| Mesh  | Feed,<br>per cent. | Grading Analysis, Discharge |              |              |              |              |              |              |              |              |              |              |              |              |              |              |              |
|-------|--------------------|-----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
|       |                    | Per<br>cent.                | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. | Per<br>cent. |
| + 20  | 6.0                |                             |              |              |              |              |              |              |              |              |              |              |              |              |              |              |              |
| + 30  | 20.0               |                             |              |              |              |              |              |              |              |              |              |              |              |              |              |              |              |
| + 40  | 24.0               |                             |              |              |              |              |              |              |              |              |              |              |              |              |              |              |              |
| + 60  | 23.0               | 42.5                        | 46.5         | 42.0         | 32.0         | 29.0         | 18.0         | 3.5          | 4.0          | 9.0          | 6.0          | 6.0          | 3.0          | 4.0          | 3.0          | 5.0          | 8.0          |
| + 80  | 11.0               |                             |              |              |              |              |              |              |              |              |              |              |              |              |              |              |              |
| + 100 | 8.0                | 27.5                        | 23.5         | 26.0         | 32.0         | 30.0         | 36.0         | 29.0         | 28.0         | 32.0         | 30.0         | 29.0         | 30.0         | 27.0         | 26.0         | 28.0         | 33.0         |
| + 120 | 4.0                |                             |              |              |              |              |              |              |              |              |              |              |              |              |              |              |              |
| + 150 | 2.0                | 8.0                         | 8.0          | 8.0          | 12.0         | 14.0         | 12.0         | 16.0         | 13.0         | 15.0         | 13.5         | 15.0         | 14.0         | 16.0         | 13.0         | 14.0         | 14.0         |
| - 150 | 2.0                | 22.0                        | 22.0         | 24.0         | 24.0         | 27.0         | 34.0         | 51.5         | 55.0         | 44.0         | 50.5         | 50.0         | 54.0         | 57.0         | 57.0         | 52.0         | 45.0         |

|                      |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Ore, per cent.       | 63.72 | 70.17 | 74.29 | 60.00 | 65.38 | 66.67 | 66.67 | 66.67 | 71.88 | 71.88 | 71.88 | 70.37 | 70.96 | 68.18 | 66.67 | 70.00 | 68.00 |
| Solution, per cent.  | 36.28 | 29.83 | 25.71 | 40.00 | 34.62 | 33.33 | 33.33 | 33.33 | 28.12 | 28.12 | 28.12 | 29.63 | 29.04 | 31.82 | 33.33 | 30.00 | 32.00 |
| Indicated horsepower | 18.80 | 20.37 | 22.50 | 32.16 | 39.13 | 42.88 | 47.16 | 51.45 | 56.28 | 60.10 | 65.39 | 77.18 | 68.61 | 69.88 | 75.04 | 68.60 | 64.85 |
| Pebble load, tons    | 1½    | 3     | 4½    | 6     | 7½    | 8½    | 9     | 9½    | 10    | 10½   | 11    | 11½   | 12    | 12½   | 12½   | 13    | 13½   |

**Pebble Load** in tube mills is generally kept at slightly above the mill center line, but fluctuations in volume above or below this amount are permissible to allow for increased or decreased tonnage being handled, or to permit variation in grinding fineness. When the level rises considerable above the center line, however, there is a danger of pebbles being "thrown back" from the feed scoop, or of chokage of the discharge screens. Figures showing the difference in horsepower consumption and other data as a result of variation in pebble volume are given in Table LXX. Weight of tube-mill pebble loads is given in Table LXXI.

TABLE LXXI.—WEIGHT OF TUBE-MILL PEBBLE LOADS<sup>65</sup>

In Tons of Pebbles at 105 lb. Per Cubic Foot

| Pebble load in 22-ft.<br>tube mill                     | Internal diameter of tube-mill lining |        |        |        |        |        |        |        |        |        |  |
|--------------------------------------------------------|---------------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--|
|                                                        | 54 in.                                | 55 in. | 56 in. | 57 in. | 58 in. | 59 in. | 60 in. | 61 in. | 62 in. | 63 in. |  |
| 12 in. above axis of mill . . .                        | 14.21                                 | 14.65  | 15.10  | 15.55  | 16.02  | 16.48  | 16.96  | 17.44  | 17.92  | 18.42  |  |
| 11 in. above axis of mill . . .                        | 13.81                                 | 14.25  | 14.69  | 15.14  | 15.59  | 16.05  | 16.51  | 16.98  | 17.46  | 17.94  |  |
| 10 in. above axis of mill . . .                        | 13.41                                 | 13.84  | 14.27  | 14.71  | 15.15  | 15.60  | 16.06  | 16.52  | 16.99  | 17.47  |  |
| 9 in. above axis of mill . . .                         | 13.01                                 | 13.43  | 13.85  | 14.28  | 14.71  | 15.16  | 15.60  | 16.06  | 16.52  | 16.98  |  |
| 8 in. above axis of mill . . .                         | 12.60                                 | 13.01  | 13.42  | 13.84  | 14.27  | 14.70  | 15.14  | 15.59  | 16.04  | 16.50  |  |
| 7 in. above axis of mill . . .                         | 12.18                                 | 12.58  | 12.99  | 13.40  | 13.82  | 14.24  | 14.67  | 15.11  | 15.56  | 16.01  |  |
| 6 in. above axis of mill . . .                         | 11.76                                 | 12.15  | 12.55  | 12.95  | 13.36  | 13.78  | 14.20  | 14.63  | 15.07  | 15.51  |  |
| 5 in. above axis of mill . . .                         | 11.33                                 | 11.72  | 12.11  | 12.50  | 12.90  | 13.31  | 13.73  | 14.15  | 14.58  | 15.01  |  |
| 4 in. above axis of mill . . .                         | 10.90                                 | 11.28  | 11.66  | 12.05  | 12.44  | 12.84  | 13.25  | 13.66  | 14.08  | 14.51  |  |
| 3 in. above axis of mill . . .                         | 10.47                                 | 10.79  | 11.21  | 11.59  | 11.98  | 12.37  | 12.77  | 13.17  | 13.59  | 14.00  |  |
| 2 in. above axis of mill . . .                         | 10.04                                 | 10.40  | 10.76  | 11.14  | 11.51  | 11.90  | 12.29  | 12.68  | 13.09  | 13.50  |  |
| 1 in. above axis of mill . . .                         | 9.60                                  | 9.96   | 10.31  | 10.68  | 11.05  | 11.42  | 11.80  | 12.19  | 12.59  | 12.99  |  |
| Level with axis of mill (i.e.,<br>half full) . . . . . | 9.18                                  | 9.53   | 9.88   | 10.23  | 10.60  | 10.96  | 11.34  | 11.72  | 12.11  | 12.50  |  |
| 1 in. below axis of mill . . .                         | 8.77                                  | 9.10   | 9.45   | 9.79   | 10.14  | 10.51  | 10.88  | 11.25  | 11.63  | 12.01  |  |
| 2 in. below axis of mill . . .                         | 8.33                                  | 8.66   | 9.00   | 9.33   | 9.69   | 10.03  | 10.39  | 10.76  | 11.13  | 11.50  |  |
| 3 in. below axis of mill . . .                         | 7.90                                  | 8.27   | 8.55   | 8.88   | 9.22   | 9.56   | 9.91   | 10.27  | 10.63  | 11.00  |  |
| 4 in. below axis of mill . . .                         | 7.47                                  | 7.78   | 8.10   | 8.42   | 8.76   | 9.09   | 9.43   | 9.78   | 10.14  | 10.49  |  |
| 5 in. below axis of mill . . .                         | 7.04                                  | 7.34   | 7.65   | 7.97   | 8.30   | 8.62   | 8.95   | 9.29   | 9.64   | 9.99   |  |
| 6 in. below axis of mill . . .                         | 6.61                                  | 6.91   | 7.21   | 7.52   | 7.84   | 8.15   | 8.48   | 8.81   | 9.15   | 9.49   |  |
| 7 in. below axis of mill . . .                         | 6.19                                  | 6.48   | 6.77   | 7.07   | 7.38   | 7.69   | 8.01   | 8.33   | 8.66   | 8.99   |  |
| 8 in. below axis of mill . . .                         | 5.77                                  | 6.05   | 6.34   | 6.63   | 6.93   | 7.23   | 7.54   | 7.85   | 8.18   | 8.50   |  |
| 9 in. below axis of mill . . .                         | 5.36                                  | 5.63   | 5.91   | 6.19   | 6.49   | 6.77   | 7.08   | 7.38   | 7.70   | 8.02   |  |
| 10 in. below axis of mill . . .                        | 4.96                                  | 5.22   | 5.49   | 5.76   | 6.05   | 6.33   | 6.62   | 6.92   | 7.23   | 7.53   |  |
| 11 in. below axis of mill . . .                        | 4.56                                  | 4.81   | 5.07   | 5.33   | 5.61   | 5.88   | 6.17   | 6.46   | 6.76   | 7.06   |  |
| 12 in. below axis of mill . . .                        | 4.16                                  | 4.41   | 4.66   | 4.92   | 5.18   | 5.45   | 5.72   | 6.00   | 6.30   | 6.58   |  |

The **Speed** of a tube mill is usually calculated from Davidsen's formula,  $N = \frac{200}{D}$ , where  $N$  equals the revolutions per minute, and  $D$  the inside diameter of the mill in inches.

**Approximate Horsepower** consumed in tube milling, where speed is regulated by Davidsen's formula, equals  $0.15 M$ , where  $M$  refers to the pebble contents of the mill in cubic feet. Moisture percentage in the feed and other factors will influence the result.

**Feed Tonnage in Tube Mills** usually varies with immediate conditions, and results are interdependent with other factors. A return system for unground product is imperatively necessary where sliming is practised, and the feed should be in such quantity that ample unground material remains near the discharge end to provide work for the falling pebbles, and to prevent undue wear on the liners. Figures showing the effect of tonnage variation in tube-mill feed are given in Table LXXII.

TABLE LXXII.—EFFECT OF FEED TONNAGE VARIATION IN TUBE MILLING<sup>64</sup>

| Size of mill            |       | 23 ft. × 5 ft. |        |        |       |       |        |        |  |
|-------------------------|-------|----------------|--------|--------|-------|-------|--------|--------|--|
| Pebble load             |       | 20,000 lb.     |        |        |       |       |        |        |  |
| Feed.....               | 3 in. | 3 in.          | 3½ in. | 3½ in. | 4 in. | 4 in. | 4½ in. | 4½ in. |  |
| Tons ore per 24 hr. . . | 172   | 172            | 190    | 190    | 216   | 216   | 231    | 231    |  |
| Percentage ore.....     | 64.71 | 66.67          | 71.05  | 67.85  | 68.18 | 69.70 | 66.67  | 72.22  |  |
| Percentage solution..   | 35.29 | 33.33          | 28.95  | 32.14  | 31.82 | 30.30 | 33.33  | 27.78  |  |
| Indicated h.p.....      | 56.4  | 54.28          | 51.60  | 54.80  | 53.20 | 49.40 | 47.50  | 43.50  |  |

| Mesh | Feed      | Discharge, Grading Analysis |           |           |           |           |           |           |           |
|------|-----------|-----------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|      | Per cent. | Per cent.                   | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| + 20 | 6.0       |                             |           |           |           |           |           |           |           |
| + 30 | 20.0      |                             |           |           |           |           |           |           |           |
| + 40 | 24.0      |                             |           |           |           |           |           |           |           |
| + 60 | 23.0      | 7.0                         | 13.0      | 12.5      | 14.0      | 16.0      | 14.0      | 26.0      | 30.0      |
| + 80 | 11.0      |                             |           |           |           |           |           |           |           |
| +100 | 8.0       | 32.0                        | 35.0      | 36.0      | 34.0      | 34.0      | 36.0      | 38.0      | 30.0      |
| +120 | 4.0       |                             |           |           |           |           |           |           |           |
| +150 | 2.0       | 13.0                        | 11.0      | 10.0      | 12.0      | 14.0      | 16.0      | 11.0      | 10.0      |
| -150 | 2.0       | 48.0                        | 41.0      | 41.5      | 40.0      | 36.0      | 34.0      | 30.0      | 30.0      |

**Moisture Percentage** in tube-mill feed is generally kept at about 38 per cent., but efficiency figures of actual practice, from which such a figure may be derived, are usually based on operations where tube-mill feed is composed of comparatively fine material. Where very coarse crushing is practised previous to tube milling, it is often found advisable to reduce the moisture below the generally-accepted percentage, as otherwise the lifted pebbles tend to drop the coarser particles of ore attached, to the detriment of crushing efficiency. The general effects of moisture variation are shown in Table LXXIII.

**General Tube-Milling Data**, referring to the details of operation of these machines in various mills, are given in Tables LXXIV and LXXV.

TABLE LXXIII.—EFFECT OF MOISTURE PERCENTAGE VARIATION IN TUBE MILLING<sup>64</sup>

|                       |                |       |       |       |       |       |       |       |       |       |       |  |
|-----------------------|----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|--|
| Size of mill          | 23 ft. × 5 ft. |       |       |       |       |       |       |       |       |       |       |  |
| Pebble load           | 20,000 lb.     |       |       |       |       |       |       |       |       |       |       |  |
| Tons ore per 24 hr.   | 172            |       |       |       |       |       |       |       |       |       |       |  |
| Ore feed              | 3 in.          |       |       |       |       |       |       |       |       |       |       |  |
| Ore, per cent.....    | 71.43          | 69.06 | 65.67 | 65.20 | 63.78 | 60.70 | 60.44 | 55.71 | 47.10 | 45.40 | 38.90 |  |
| Solution, per cent... | 28.57          | 30.44 | 34.33 | 34.80 | 36.22 | 39.30 | 39.56 | 44.29 | 52.90 | 54.60 | 61.10 |  |
| Indicated h.p.....    | 45.0           | 48.9  | 55.8  | 57.4  | 58.0  | 56.9  | 55.0  | 55.8  | 59.0  | 62.3  | 62.3  |  |

| Mesh | Feed      | Discharge, Grading Analysis |           |           |           |           |           |           |           |           |           |           |
|------|-----------|-----------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
|      | Per cent. | Per cent.                   | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| + 20 | 6.0       |                             |           |           |           |           |           |           |           |           |           |           |
| + 30 | 20.0      |                             |           |           |           |           |           |           |           |           |           |           |
| + 40 | 24.0      |                             |           |           |           |           |           |           |           |           |           |           |
| + 60 | 23.0      | 12.5                        | 13.0      | 8.0       | 8.0       | 9.0       | 8.0       | 7.0       | 8.0       | 7.0       | 5.5       | 8.0       |
| + 80 | 11.0      |                             |           |           |           |           |           |           |           |           |           |           |
| +100 | 8.0       | 36.0                        | 34.0      | 30.0      | 32.0      | 33.0      | 33.0      | 31.0      | 34.0      | 32.0      | 30.5      | 32.0      |
| +120 | 4.0       |                             |           |           |           |           |           |           |           |           |           |           |
| +150 | 2.0       | 10.0                        | 12.0      | 13.0      | 14.0      | 12.0      | 13.0      | 13.0      | 12.0      | 14.0      | 13.0      | 12.0      |
| -150 | 2.0       | 41.5                        | 41.0      | 49.0      | 46.0      | 46.0      | 46.0      | 50.0      | 46.0      | 47.0      | 41.0      | 48.0      |

TABLE LXXIV.—COMPARATIVE

| Company                                    | When published | Number of mills | Make             | Size                 | Volume, cu. ft. | R.p.m. | Capacity, tons per 24 hr. |
|--------------------------------------------|----------------|-----------------|------------------|----------------------|-----------------|--------|---------------------------|
| Oroya Brownhill, W. Australia...           | 1904           | 5               |                  | Inside<br>3'8"×13'7" | 143             |        | 37.5 thru 200             |
| Hannans Star, W. Australia....             | 1904           |                 |                  | 4'×16'               | 201             | 29     | 38, 95%—15C mesh          |
| Yuanmi, W. Australia.....                  | 1912           | 1               |                  | 4'×16'               | 201             |        | 34, 150                   |
| Waihi, New Zealand.....                    | 1911           | 3               |                  | Inside<br>4'9"×18'   | 319             | 25—26  | 110, 120                  |
| Rand, South Africa.....                    | 1912           |                 |                  | 5'6"×22'             | 523             |        | 130 thru 90-mesh          |
| Rand, South Africa.....                    | —              | 8               |                  | 5'6"×22'             | 523             | 28     | 240, 90%—90               |
| Dos Estrellas, El Oro, Mex.....            | 1909           | 4               | Allis-Chalmers   | 5'×24'               | 471             | 28     | 75, 58%—200               |
| Esperanza, El Oro, Mex.....                | 1912           | 10              | Krupp            | Inside<br>48¾"×19'8" | 250             | 32     | 40                        |
| Santa Gertrudis, Pachuca, Mex..            | 1912           | 6               |                  | 5'×16'               | 314             |        |                           |
|                                            |                | 4               |                  | 5'×20'               | 392             |        |                           |
| Mexico, Mines of, El Oro, Mex..            | 1912           | 6               | Krupp            | 4'×20'               | 250             | 31     | 50, 60<br>90%—200         |
| Lucky Tiger, Sonora, Mex.....              | 1912           | 5               | P. and M. M. Co. | 5'×14'               | 274             |        | 51, 85%—200               |
| Montana-Tonopah, Nev.....                  | 1908           | 2               | Allis-Chalmers   | 5'×22'               | 432             | 27     | 52,<br>66%—200            |
| Goldfield Con., Goldfield, Nev.,           | 1912           | 6               | A. C.            | 5'×22'               | 432             |        |                           |
| Black Oak, Tuolumne Co., Calif.            | 1912           | 1               |                  | 5'×18'               | 353             | 23     |                           |
| Liberty Bell, Telluride, Colo....          | 1913           | 3               | Abbé             | 5'×22'               | 432             |        |                           |
| Hollinger, Porcupine, Ont., Can..          | 1912           | 4               | A. C.            | 5'×20'               | 392             | 28     | 90,<br>90%—200            |
| Dome, Porcupine, Ontario.....              | 1912           | 4               | A. C.            | 5'×22'               | 432             | 32     |                           |
| New Nipissing, Low Grade, Cobalt, Ont..... | 1913           | 4               |                  | 6½'×22'              |                 |        |                           |
| Cement Industry.....                       | 1912           |                 |                  | 5'×22'               | 432             |        |                           |



TUBE-MILL PRACTICE<sup>66</sup>

| H.p.<br>con-<br>sumed | Pebbles           | Lb.<br>pebbles,<br>per ton | Cost,<br>pebbles<br>per ton | Kind of<br>lining | Cost<br>of<br>lining | Total<br>cost<br>per ton<br>milled | Remarks                             |
|-----------------------|-------------------|----------------------------|-----------------------------|-------------------|----------------------|------------------------------------|-------------------------------------|
| 17                    |                   |                            |                             | Hard iron         |                      | \$0.421                            | Power cost \$0.099.                 |
| 30                    | 5.5 Tons<br>Flint |                            |                             |                   |                      | 0.436                              |                                     |
| 30-35                 |                   |                            |                             | Corrugated        |                      |                                    | Feed 70% + 100<br>mesh              |
|                       | Flint             |                            |                             | Mn steel          |                      |                                    | 24% - 150                           |
| 55                    | 5.5 Tons          |                            |                             | Cast iron         |                      |                                    |                                     |
| 75-90                 | Flint             | 2.6                        | \$0.017                     | Ribbed            | \$0.011              | 0.094                              | Feed 10 mesh                        |
|                       | 8-14 tons         |                            |                             |                   |                      |                                    | 1½ tons per h.p.                    |
|                       | Quartz            |                            |                             | Silex             |                      |                                    | (from ball) thru 90<br>mesh         |
| 108                   | 13 tons           |                            |                             | Ribbed            |                      |                                    | Feed 3 mesh (0.29")                 |
|                       | Quartz            |                            |                             | El Oro            |                      | 0.156                              | Lining lasts 300 days               |
|                       | Quartz            | 15                         |                             |                   |                      |                                    |                                     |
| 40                    | Quartz            |                            |                             | Ribbed            |                      |                                    | Feed largely quartz<br>and tailings |
|                       |                   |                            |                             |                   |                      |                                    |                                     |
|                       | Quartz            |                            |                             | El Oro            |                      |                                    |                                     |
| 43-48                 | Flint             | 8.7                        |                             | Ribbed            |                      | 0.65                               | Feed 0.75 mm.                       |
| 42.5                  |                   | 2.2                        | 0.055                       | 4" Silex          | 0.069                | 0.358                              | Lining lasted 8 mos.                |
| 60                    |                   | 1.8                        |                             | Silex             | 0.023                | 0.166                              | Silex lasts 7 mos.                  |
| 43                    |                   |                            |                             | Ribbed            |                      |                                    | Silent chain drive                  |
|                       | Flint             |                            |                             | 4" Silex          |                      | 0.0769                             | Lining lasts 9-10<br>mos.           |
|                       | Flint             |                            |                             | Silex             |                      |                                    | Silent chain drive                  |
|                       |                   |                            |                             |                   |                      |                                    |                                     |
| 70-80                 | Flint             |                            |                             |                   |                      |                                    | Product from ball<br>mills          |

TABLE LXXV.—TUBE-MILL DATA<sup>49</sup>

|                       | Tons milled per 24 hr. | No. of tubes | Dimensions, ft. | H.p. hr. per ton milled | Cost per ton milled, cents | Final product      |                    |
|-----------------------|------------------------|--------------|-----------------|-------------------------|----------------------------|--------------------|--------------------|
|                       |                        |              |                 |                         |                            | %—100 (0.0055 in.) | %—200 (0.0029 in.) |
| Mex. Silver Mill..... | 1000                   | 6            | 5 × 16          | ....                    | ....                       | ....               | ....               |
|                       |                        | 6            | 5 × 20          | 19.2                    | 22.0                       | 98.0               | 75.0               |
| Nipissing.....        | 245                    | 4            | 6 × 20          | 44.6                    | 50.0                       | 100.0              | 100.0              |
| Belmont.....          | 500                    | 7            | 5 × 18          | 16.8                    | 40.9                       | 99.0               | 72.3               |
| Silver Peak.....      | 500                    | 1            | 5 × 18          | 2.4                     | 2.6                        | 64.0               | 50.0               |
| Homestake.....        | 4500                   | 2            | 5 × 14          | ....                    | ....                       | ....               | ....               |
|                       |                        | 2            | 5 × 18          | 0.8                     | 1.2                        | 87.0               | 66.0               |
| Hollinger.....        | 585                    | 6            | 5 × 20          | 16.0                    | 18.8                       | 100.0              | 90.0               |
| Porcupine Crown.....  | 150                    | 1            | 5 × 16          | ....                    | ....                       | ....               | ....               |
|                       |                        | 1            | 4 × 20          | 11.5                    | 36.0                       | 100.0              | 90.0               |
| Liberty Bell.....     | 485                    | 3            | 5 × 22          | 4.3                     | 7.7                        | 87.0               | 73.4               |

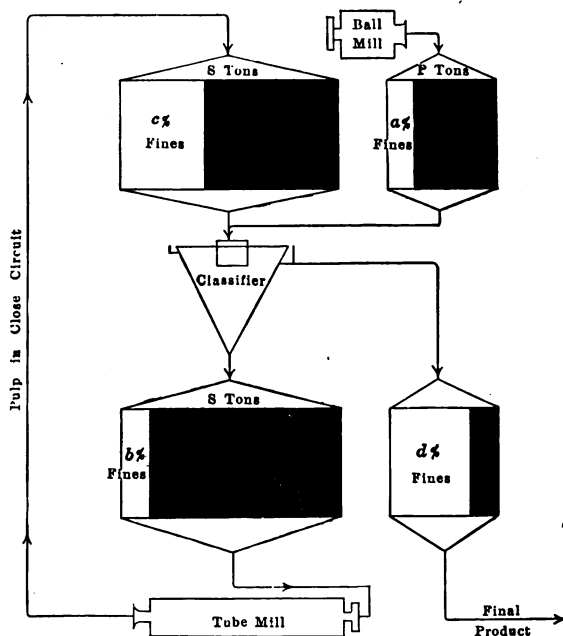


FIG. 129.—Close-circuit diagram.

The **Tonnage** of ore circulating in a **Close-Circuit Grinding System** is a factor in the maintenance of high crushing efficiency. The calculation is, therefore, desirable. A number of formulæ have been evolved by various methods of calculation to aid in estimating the amount by means of screening analyses, as originally suggested by Noel Cunningham. A simple method is to equate tonnage of fine product (*i.e.*, through a certain mesh) obtained by subtracting the amount found in the feed to, from the amount found in the discharge from, the secondary crushers, with the difference in amount in the pulp from the primary crushers and the final product. This is shown graphically in Fig. 129. If  $P$  equals tonnage from primary crushers to classifiers and containing  $a$  per cent. of material passing a particular mesh;  $S$  equals tonnage to and from the secondary plant, entering with  $b$  per cent. and leaving with  $c$  per cent. of material of the same fineness; and if  $d$  per cent. equals the percentage of fines in the final product, then:

$$\begin{aligned}\text{Tons of fines produced} &= Sc - Sb \\ &= Pd - Pa\end{aligned}$$

Therefore  $S$ , the tonnage circulating through the secondary plant

$$= \frac{P(d - a)}{c - b}$$

For example: the diagram may be used to represent an instance where the original feed from a ball mill amounted to 40 tons ( $P$ ) containing 25 per cent. ( $a$ ), or 10 tons, of material passing a certain mesh. This product joins the discharge from the tube mill, the mixture is classified, and a coarse material containing 12.5 per cent. ( $b$ ) of fines goes to the tube mill. The percentage of fines increases during grinding to 37.5 per cent. ( $c$ ), and the final product leaving the classifier is found to contain 75 per cent. ( $d$ ). Hence:  $S$ , the tonnage in close circuit,

$$\begin{aligned}&= \frac{P(d - a)}{c - b} \\ &= \frac{40(75 - 25)}{37.5 - 12.5} \\ &= 80\end{aligned}$$

The circulating tonnage is, therefore, twice the original tonnage—a fact that is visually evident from a glance at the diagram.

## SECTION XIII

### CONVEYANCE AND ELEVATION OF ORE PULP

**Pulp Elevation Problems** are governed by the factors of ore coarseness, specific gravity of fluid, and elevation required. Owing to the varied conditions of work and the different characteristics of the material to be elevated, the principal requirement is suitability; *i.e.*, the system and equipment installed should involve minimum attention for control and repair, and must operate at a satisfactory efficiency. Elevation of pulp and water are phases of ore-dressing work in which continuity of operation is of primary importance, and for this reason every opportunity should be taken advantage of in the first instance to install equipment which will do the work efficiently and without unnecessary attention. The question of loss of time to effect repairs and renewals should also be considered. Such apparatus may be divided into nine divisions, according to the class of material to be handled and the height to which it must be elevated. Table LXXVI shows the applicability of eight classes of apparatus for different kinds of work.

TABLE LXXVI.—MILL PUMPING SYSTEMS<sup>67</sup>

| Material to be pumped | Low lift<br>(to 25 ft.)                      | Medium lift<br>(to 50 ft.)            | High lift<br>(to 100 ft. or more)                              |
|-----------------------|----------------------------------------------|---------------------------------------|----------------------------------------------------------------|
| Water or solution     | Air lift<br>Frenier pump<br>Centrifugal pump | Centrifugal pump<br>Compound air lift | Plunger pump (1-, 2-, or 3-throw)<br>Compound centrifugal pump |
| Slime pulp            | Air lift<br>Diaphragm pump<br>Frenier pump   | Compound air lift<br>Centrifugal pump | Plunger pump (1-, 2-, or 3-throw)                              |
| Sand pulp             | Centrifugal pump<br>Air lift<br>Frenier pump | Centrifugal pump<br>Tailings wheel    | Plunger pump (3-throw)                                         |

The simple **Centrifugal Pump** is largely used for the elevation of water and ore pulp. For low lifts it is favored on account of compactness, and because it can be direct connected to an electric motor. Normal velocity for this type of pump is high, even with low lifts. Hence the greater ability of the centrifugal to keep grains of sand in suspension until the discharge point is reached. If there is a tendency for the solid matter in the pulp to settle quickly, the centrifugal should be adopted. It is not suitable if dilution with gland clearance water must be avoided. For medium lifts the centrifugal has its disadvantages. Considerable trouble is often caused by the wear of liners and runners,

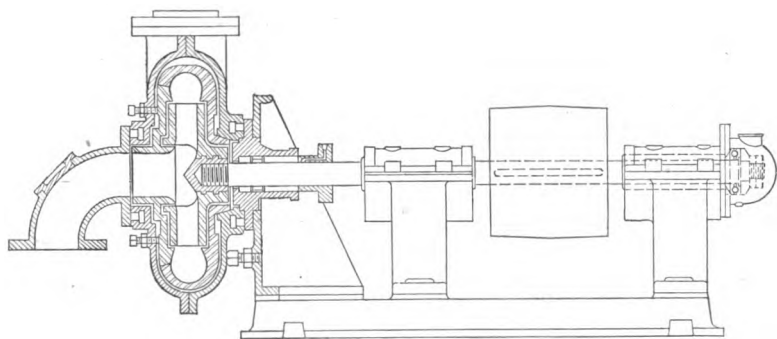


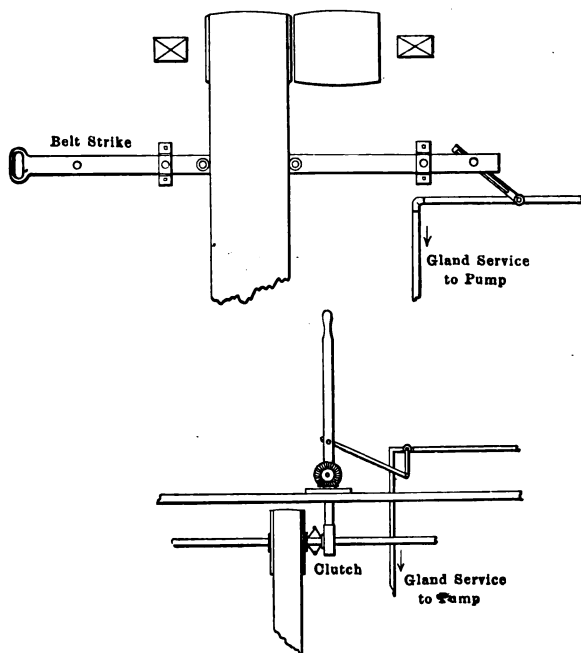
FIG. 130.—Centrifugal sand pump.<sup>68</sup>

on account of the comparatively high speed necessary for effective operation. The wear causes uncertain delivery long before it is time to hang up for repairs. If continuity of operation is desired it is imperatively necessary to erect in duplicate, so that a second pump will always be available in case of breakdown. A standard type of centrifugal pump is shown in Fig. 130.

**Centrifugal Pump Runner Speed** is designed in definite ratio to height of lift. High lifts involve excessive speed, and this results in considerable friction, and wear on the liners. The single-type pump is, therefore, unsuitable for the purpose. Details of centrifugal pump operation are given in Table LXXVII.

TABLE LXXVII.—CENTRIFUGAL PUMP OPERATION<sup>69</sup>

| No. pump (diam. discharge) | Horsepower for each foot head | Nominal capacity gal. per min. | Diameter and face of pulley, inches | Floor space, in. | Shipping weight, pounds | Rev. per minute for given heads |        |        |        |        |        | No. pump |
|----------------------------|-------------------------------|--------------------------------|-------------------------------------|------------------|-------------------------|---------------------------------|--------|--------|--------|--------|--------|----------|
|                            |                               |                                |                                     |                  |                         | 10 ft.                          | 20 ft. | 30 ft. | 40 ft. | 50 ft. | 60 ft. |          |
| 2                          | 0.1                           | 110                            | 8 × 8                               | 46 × 20          | 625                     | 505                             | 715    | 875    | 1005   | 1125   | 1230   | 2        |
| 3                          | 0.22                          | 260                            | 10 × 10                             | 47 × 27          | 1050                    | 400                             | 570    | 700    | 805    | 910    | 985    | 3        |
| 4                          | 0.35                          | 450                            | 12 × 10                             | 48 × 29          | 1150                    | 435                             | 610    | 745    | 865    | 970    | 1055   | 4        |
| 5                          | 0.5                           | 700                            | 14 × 10                             | 59 × 33          | 2000                    | 400                             | 570    | 700    | 805    | 910    | 985    | 5        |
| 6                          | 0.68                          | 1000                           | 14 × 12                             | 60 × 38          | 2400                    | 340                             | 475    | 580    | 670    | 750    | 815    | 6        |
| 7                          | 0.86                          | 1350                           | 18 × 14                             | 74 × 44          | 3200                    | 320                             | 450    | 545    | 635    | 710    | 775    | 7        |
| 8                          | 1.2                           | 1800                           | 20 × 14                             | 75 × 47          | 4300                    | 290                             | 410    | 500    | 575    | 640    | 700    | 8        |
| 10                         | 1.9                           | 2800                           | 22 × 16                             | 84 × 50          | 5200                    | 315                             | 445    | 540    | 630    | 705    | 770    | 10       |
| 10                         | 1.9                           | 2800                           | 24 × 16                             | 90 × 60          | 7000                    | 240                             | 340    | 415    | 480    | 540    | 590    | 10       |
| 12                         | 2.5                           | 4000                           | 24 × 16                             | 92 × 63          | 9400                    | 220                             | 315    | 380    | 440    | 490    | 540    | 12       |

FIG. 131.—Automatic regulation of pump-gland clearance service.<sup>70</sup>

**Clearance Water under Pressure** is an essential precaution to keep grit from the packing in plunger or centrifugal pumps handling sand or slime. To insure the water being turned on when the pump is started the schemes illustrated in Fig. 131 are recommended.

**Diaphragm Suction Pumps** (Fig. 132) are largely superseding the air lift for low-lift slime-pulp elevation. An adjustable length of stroke makes regulation satisfactory. The ability

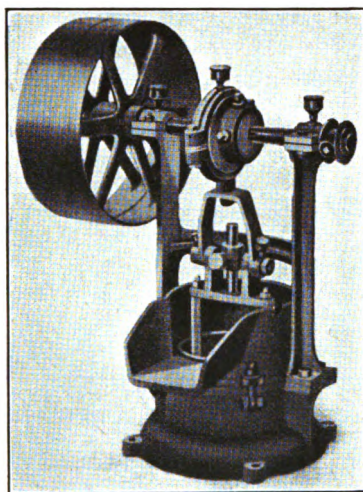


FIG. 132.—Diaphragm suction pump.<sup>31</sup>

of this type of pump to counterbalance the difference between the static head of the average of the thin pulp in a tank or vat, and the thick pulp at the discharge, without loss of fall, has resulted in its wide adoption to handle the discharge from mechanical thickeners, particularly those of the Dorr continuous type. The height of lift is exceedingly limited. Table LXXVIII gives theoretical possible lifts, but owing to the slow speed at which the pump operates and the fact that entangled air is usually present in the pulp there is a difficulty in maintaining the vacuum under normal conditions. The limits in practice

are usually from 50 to 75 per cent. of those given in the table. Heating the pulp or diluent is often a necessary phase of operations in a milling plant. The effect of this on diaphragm-pump operation may be estimated by reference to Table LXXIX.

TABLE LXXVIII.—APPROXIMATE THEORETICAL SUCTION- AND DIAPHRAGM PUMP LIFTS AT NORMAL TEMPERATURES<sup>67</sup>

| Altitude, ft. | Specific gravity of fluid    |       |       |       |       |       |       |       |
|---------------|------------------------------|-------|-------|-------|-------|-------|-------|-------|
|               | 1.000                        | 1.100 | 1.200 | 1.300 | 1.400 | 1.500 | 1.600 | 1.700 |
|               | Maximum suction lift in feet |       |       |       |       |       |       |       |
| Sea level     | 34                           | 31    | 28    | 26    | 24    | 23    | 21    | 20    |
| 1,000         | 33                           | 30    | 27    | 25    | 23    | 22    | 21    | 19    |
| 2,000         | 32                           | 29    | 26    | 24    | 22    | 21    | 20    | 18    |
| 3,000         | 31                           | 28    | 25    | 23    | 22    | 20    | 19    | 18    |
| 4,000         | 29                           | 27    | 24    | 23    | 21    | 20    | 18    | 17    |
| 5,000         | 28                           | 26    | 23    | 22    | 20    | 19    | 18    | 17    |
| 6,000         | 27                           | 25    | 22    | 21    | 19    | 18    | 17    | 16    |
| 7,000         | 26                           | 24    | 21    | 20    | 19    | 17    | 17    | 16    |
| 8,000         | 25                           | 23    | 21    | 19    | 18    | 16    | 16    | 15    |
| 9,000         | 24                           | 22    | 20    | 18    | 17    | 16    | 16    | 14    |
| 10,000        | 23                           | 21    | 19    | 18    | 17    | 16    | 15    | 14    |

TABLE LXXIX.—EFFECT OF TEMPERATURE ON SUCTION- AND DIAPHRAGM PUMP LIFTS<sup>67</sup>

| Deg. Fahr. | Approximate theoretical suction lift in feet, for water, at sea level | Deg. Fahr. | Approximate theoretical suction lift in feet, for water, at sea level |
|------------|-----------------------------------------------------------------------|------------|-----------------------------------------------------------------------|
| 60         | 34                                                                    | 140        | 27                                                                    |
| 80         | 33                                                                    | 160        | 23                                                                    |
| 100        | 32                                                                    | 180        | 16                                                                    |
| 120        | 30                                                                    | 200        | 8                                                                     |

**Plunger Pumps** are compact and suitable machines for ore-pulp elevation. Single-plunger pumps cannot be used, however, with any success with a pulp carrying rapid-settling particles. The three-throw type is to be preferred and is generally used. Hinged clack valves are unsuitable in any case. For continuous opera-



tion a plunger pump may draw from a sump placed below the level of the pump, within suction limits, but a gravity supply into the suction is to be preferred and is almost imperatively necessary with intermittent operation. Pressure clearance water, delivered to the plunger chamber below the packing,

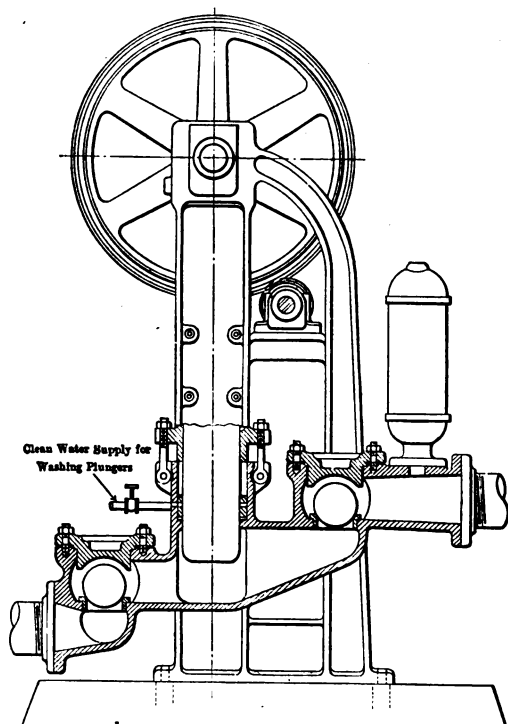


FIG. 133.—Aldrich three-throw slime pump.<sup>71</sup>

is essential to prevent undue wear on the plungers. The speed of the pump is a factor depending upon the character of the solids being lifted. This class of pump is not altogether suitable for coarse-ore pulp, but in the case where it is used for this purpose the velocity of flow should be sufficient to prevent aggregation of sand and consequent chokage in any part of the system.

The **Aldrich Three-Throw Slime Pump** is shown in Fig. 133. Ball valves are used in this pump, and on account of compactness, accessibility of parts, and general construction, the type is to be recommended. Details of operation are given in Table LXXX.

TABLE LXXX.—ALDRICH SLIME PUMP OPERATION<sup>71</sup>

| Maximum capacity in U. S. gallons per min. | Maximum pump speed in rev. per min. | Size of pump       |             | Size of suction and discharge | Maximum working lift, 100 ft.                                        |                                       |
|--------------------------------------------|-------------------------------------|--------------------|-------------|-------------------------------|----------------------------------------------------------------------|---------------------------------------|
|                                            |                                     | Plunger diam., in. | Stroke, in. |                               | Size of tight and loose pulleys, in. Pulleys figured for double belt | Pulley rev. per min. at max. capacity |
| 14                                         | 40                                  | 3                  | 4           | 2                             | 10 × 3                                                               | 200                                   |
| 20                                         | 40                                  | 3½                 | 4           | 2½                            | 10 × 3                                                               | 200                                   |
| 50                                         | 40                                  | 5                  | 5           | 3                             | 12 × 3                                                               | 200                                   |
| 70                                         | 40                                  | 5                  | 7           | 4                             | 15 × 3                                                               | 200                                   |
| 100                                        | 40                                  | 6                  | 7           | 5                             | 18 × 4                                                               | 200                                   |
| 130                                        | 40                                  | 6                  | 9           | 5                             | 20 × 4                                                               | 200                                   |
| 180                                        | 40                                  | 7                  | 9           | 6                             | 24 × 5                                                               | 200                                   |
| 300                                        | 40                                  | 8½                 | 10          | 7                             | 30 × 5                                                               | 200                                   |

The **Air Lift** operates on the principle that a column of ore pulp plus air is lighter than an equivalent column of ore pulp. The lifting action is accelerated by the gradual expansion of the air from maximum to atmospheric pressure, which results in a decrease in the specific gravity of the mixture as it rises in the lift pipe.

A **Compound Air Lift** consists of two or more simple air lifts arranged in series, the rising main of the first discharging into the sump of the second, and so on. The system can be used to duplicate or triplicate any of the ordinary designs in use. It is suitable where a sump of sufficient depth would be impracticable, or where the available pressure of air is low.

**Failure with Air Lifts** usually results when the material lifted is too coarse. Efficiency is often sacrificed by using excess air

volume and pressure as a remedy for defective design. Precautions to be avoided have been stated as follows:

- (i) An insufficient or an excessive allowance in the ratio of submergence to lift.
- (ii) Lack of precautions providing for the intimate mixture of air and pulp at the lift intake.
- (iii) The use of bends or elbows in the discharge pipe.
- (iv) An unnecessary air pressure or volume.
- (v) High velocity in the rising main.

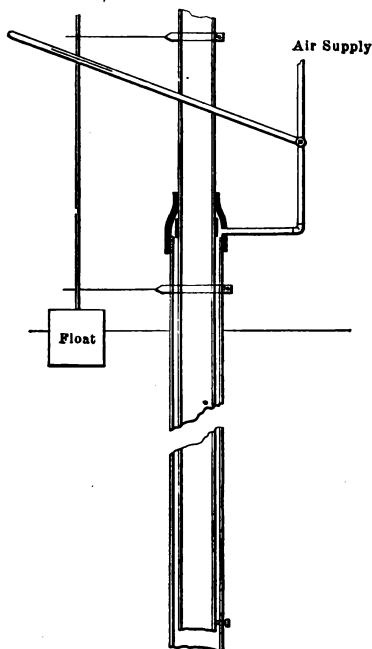


FIG. 134.—Air lift for slime pulp.

A Submergence of from  $1\frac{3}{4}$  times to twice the lift has been found to be the most efficient. The lift should be compounded where this submergence is not obtainable. A suitable arrangement for insuring the admixture of air and pulp at the intake is shown in Fig. 134. The air is delivered around the

bottom of the lift pipe and the danger of chokage of the air supply is almost entirely avoided. Where possible the discharge should deliver into the bottom of a short launder having a sharp fall. Pressures required for ordinary air-lift work with various specific gravities of pulp are shown in Table LXXXI. The capacities of air lifts under similar conditions are given in Table LXXXII.

TABLE LXXXI.—THEORETICAL PRESSURES REQUIRED TO ELEVATE WATER AND ORE PULP BY AIR LIFT<sup>73</sup>

| Lift, ft. | Submergence, ft. | Theoretical gauge pressure in lb. per sq. in. to elevate fluid of specific gravity |          |       |       |       |       |
|-----------|------------------|------------------------------------------------------------------------------------|----------|-------|-------|-------|-------|
|           |                  | Water                                                                              | Ore pulp |       |       |       |       |
|           |                  |                                                                                    | 1.000    | 1.100 | 1.200 | 1.300 | 1.400 |
| 5         | 7.5              | 3.2                                                                                | 3.5      | 3.8   | 4.2   | 4.5   | 4.8   |
| 10        | 15.0             | 6.5                                                                                | 7.1      | 7.8   | 8.4   | 9.1   | 9.7   |
| 15        | 22.5             | 9.7                                                                                | 10.7     | 11.6  | 12.6  | 13.6  | 14.5  |
| 20        | 30.0             | 13.0                                                                               | 14.3     | 15.6  | 16.9  | 18.2  | 19.5  |
| 25        | 37.5             | 16.2                                                                               | 17.8     | 19.4  | 21.0  | 22.7  | 24.3  |
| 30        | 45.0             | 19.5                                                                               | 21.4     | 23.4  | 25.3  | 27.3  | 29.2  |
| 35        | 52.5             | 22.7                                                                               | 25.0     | 27.2  | 29.5  | 31.8  | 34.0  |
| 40        | 60.0             | 26.0                                                                               | 28.6     | 31.2  | 33.8  | 36.4  | 39.0  |
| 45        | 67.5             | 29.2                                                                               | 32.1     | 35.0  | 38.0  | 40.9  | 43.8  |
| 50        | 75.0             | 32.5                                                                               | 35.7     | 39.0  | 42.2  | 45.5  | 48.7  |
| 5         | 10.0             | 4.3                                                                                | 4.7      | 5.2   | 5.6   | 6.0   | 6.4   |
| 10        | 20.0             | 8.7                                                                                | 9.6      | 10.4  | 11.3  | 12.2  | 13.0  |
| 15        | 30.0             | 13.0                                                                               | 14.3     | 15.6  | 16.9  | 18.2  | 19.5  |
| 20        | 40.0             | 17.3                                                                               | 19.0     | 20.8  | 22.5  | 24.2  | 25.9  |
| 25        | 50.0             | 21.6                                                                               | 23.8     | 25.9  | 28.1  | 30.2  | 32.4  |
| 30        | 60.0             | 26.0                                                                               | 28.6     | 31.2  | 33.8  | 36.4  | 39.0  |
| 35        | 70.0             | 30.3                                                                               | 33.3     | 36.4  | 39.4  | 42.4  | 45.4  |
| 40        | 80.0             | 34.6                                                                               | 38.0     | 41.5  | 45.0  | 48.4  | 51.9  |
| 45        | 90.0             | 39.0                                                                               | 42.9     | 46.8  | 50.7  | 54.6  | 58.5  |
| 50        | 100.0            | 43.3                                                                               | 47.6     | 52.0  | 56.3  | 60.6  | 64.9  |

In practice an increase over the above pressure figures of from 10 per cent. to 15 per cent. will be required.

TABLE LXXXII.—AVERAGE CAPACITY OF AIR LIFTS HANDLING ORE PULP<sup>73</sup>

| Diam. of<br>lift pipe, in. | Cu. ft.<br>per min. | Tons per 24 hr. |                          |       |       |       |       |
|----------------------------|---------------------|-----------------|--------------------------|-------|-------|-------|-------|
|                            |                     | Water           | Pulp of specific gravity |       |       |       |       |
|                            |                     |                 | 1.100                    | 1.200 | 1.300 | 1.400 | 1.500 |
| 2                          | 6                   | 270             | 297                      | 324   | 351   | 378   | 405   |
| 2½                         | 10                  | 450             | 495                      | 540   | 585   | 630   | 675   |
| 3                          | 14                  | 630             | 693                      | 756   | 819   | 882   | 945   |
| 3½                         | 20                  | 900             | 990                      | 1080  | 1170  | 1260  | 1350  |
| 4                          | 25                  | 1125            | 1237                     | 1350  | 1462  | 1575  | 1687  |
| 5                          | 40                  | 1800            | 1980                     | 2160  | 2340  | 2520  | 2700  |
| 6                          | 56                  | 2520            | 2772                     | 3024  | 3276  | 3528  | 3780  |

**The Air Volume** required for simple air lifts is shown in Table LXXXIII. For a constant length of rising main the amount of free air required decreases as the submergence increases, and increases as the lift increases. The amount of free air required does not vary materially with the weight of the pulp being lifted, other than in the case where excessive velocity in the rising main is necessary to prevent the settlement of solids. In this case the air lift is not suitable. The figures given in the table are approximate. If care is taken in the design of the lift the amount of air actually required will be found to be below the volume given; but on account of the variation of conditions under which such a system may be utilized it is advisable to allow a wide margin.

**Altitude** does not affect the efficiency of the air lift. The extra volume of free air compressed in the first instance is balanced by the extra work done as a result of the increased expansibility of the air after compression. The air should escape at little above the pressure of the surrounding atmosphere.

**The Frier Pump**, or spiral sand pump, as it is sometimes termed, operates on the air-lift principle. The proper operating speed is fixed, and the output from the pump cannot be materially raised or the lift increased by an acceleration in r.p.m. The

TABLE LXXXIII.—AIR VOLUME REQUIRED TO OPERATE AIR LIFT<sup>74</sup>

| Lift, ft. | Submergence, ft. | Size of lift pipe, cu. ft. of free air per min. |        |       |        |       |       |       |
|-----------|------------------|-------------------------------------------------|--------|-------|--------|-------|-------|-------|
|           |                  | 2 in.                                           | 2½ in. | 3 in. | 3½ in. | 4 in. | 5 in. | 6 in. |
| 5         | 7.5              | 13                                              | 22     | 31    | 45     | 56    | 90    | 126   |
| 10        | 15.0             | 15                                              | 24     | 34    | 49     | 61    | 98    | 137   |
| 15        | 22.5             | 16                                              | 26     | 37    | 53     | 66    | 105   | 147   |
| 20        | 30.0             | 17                                              | 28     | 39    | 56     | 70    | 112   | 157   |
| 25        | 37.5             | 18                                              | 30     | 42    | 60     | 75    | 120   | 167   |
| 30        | 45.0             | 19                                              | 32     | 44    | 63     | 79    | 127   | 177   |
| 35        | 52.5             | 20                                              | 33     | 47    | 66     | 83    | 133   | 186   |
| 40        | 60.0             | 21                                              | 35     | 49    | 70     | 86    | 139   | 194   |
| 45        | 67.5             | 22                                              | 36     | 51    | 73     | 90    | 145   | 202   |
| 50        | 75.0             | 22                                              | 37     | 52    | 75     | 93    | 150   | 210   |
| 5         | 10.0             | 10                                              | 17     | 24    | 35     | 43    | 69    | 97    |
| 10        | 20.0             | 11                                              | 19     | 27    | 39     | 48    | 77    | 107   |
| 15        | 30.0             | 12                                              | 21     | 30    | 42     | 53    | 85    | 117   |
| 20        | 40.0             | 13                                              | 23     | 32    | 45     | 57    | 91    | 127   |
| 25        | 50.0             | 14                                              | 25     | 35    | 49     | 61    | 98    | 136   |
| 30        | 60.0             | 15                                              | 26     | 37    | 52     | 65    | 104   | 145   |
| 35        | 70.0             | 16                                              | 28     | 39    | 56     | 69    | 111   | 154   |
| 40        | 80.0             | 17                                              | 30     | 41    | 59     | 73    | 117   | 164   |
| 45        | 90.0             | 18                                              | 31     | 43    | 62     | 77    | 123   | 173   |
| 50        | 100.0            | 19                                              | 32     | 45    | 65     | 81    | 129   | 182   |

air is compressed to a very limited pressure, and satisfactory operation is insured by operating with exactly the amount of pulp required by the pump, allowing free egress from the discharge pipe, limiting the height of lift well within the prescribed figures, and operating on a pulp as fine as possible and carrying no high percentage of heavy mineral. Figure 135 will serve to illustrate the general design, and Table LXXXIV gives average capacities. A deduction, of 4 in. for each 1000 ft., from the stated lift should be made in the case where the pump is to operate at an altitude.

**Belt-and-Bucket Elevators** are satisfactory machines for the elevation of ore pulp. The design should include provision

for the delivery of pulp into the ascending buckets, an arrangement to provide against slippage due to belt stretching, a safety

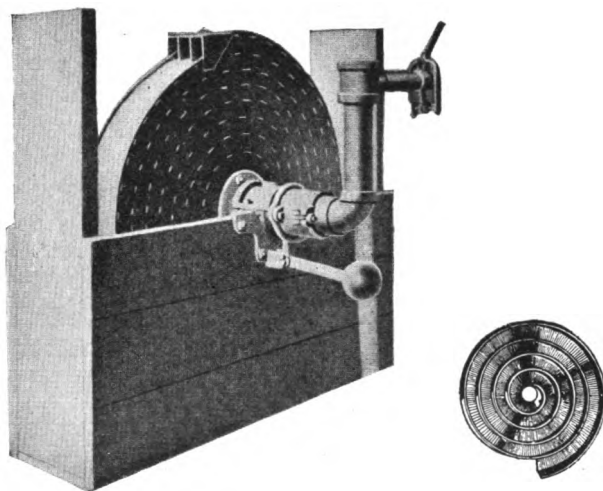


FIG. 135.—Spiral sand pump.

TABLE LXXXIV.—APPROXIMATE FRENIER PUMP CAPACITIES<sup>67</sup>

| Size, in. | Specific gravity of fluid |       |       |       |       |       |
|-----------|---------------------------|-------|-------|-------|-------|-------|
|           | 1.000                     | 1.100 | 1.200 | 1.300 | 1.400 | 1.500 |
|           | Tons per 24 hr.           |       |       |       |       |       |
| 44 × 6    | 450                       | 490   | 540   | 580   | 630   | 670   |
| 48 × 6    | 450                       | 490   | 540   | 580   | 630   | 670   |
| 54 × 6    | 450                       | 490   | 540   | 580   | 630   | 670   |
| 44 × 8    | 540                       | 590   | 650   | 700   | 760   | 810   |
| 48 × 8    | 540                       | 590   | 650   | 700   | 760   | 810   |
| 54 × 8    | 540                       | 590   | 650   | 700   | 760   | 810   |
| 44 × 10   | 630                       | 690   | 760   | 820   | 880   | 940   |
| 48 × 10   | 630                       | 690   | 760   | 820   | 880   | 940   |
| 54 × 10   | 630                       | 690   | 760   | 820   | 880   | 940   |

These capacities are based on moderate lifts, precise adjustment and maintenance of level of liquid in the box, and free discharge. If any one of these conditions is impracticable the figures should be reduced accordingly.

boot overflow discharge below the level of the lower bearings, an ample allowance in height for top discharge, and liner plates where wear and scouring action is greatest.

**The Buckets on Belt Elevators** are sometimes placed in a staggered position. This results in a more even load on the belt and less strain on the center line.

**Tailing Wheels** are costly to erect and clumsy in appearance, but cheap to operate. They are seldom adopted in countries where mills are covered in. The efficiency of a tailing wheel varies from 50 to 60 per cent., and is uniform. Under many conditions it can successfully compete with the centrifugal in the elevation of mill pulp.

**Data Dealing with Inclination and Capacity of Launderers** and piping will be found in Tables LXXXV, LXXXVI, and LXXXVII.

TABLE LXXXV.—LAUNDER GRADES AT GOLDFIELD CONSOLIDATED<sup>76</sup>

| Product                                         | Dilution | Width of launder, in. | Height of launder, in. | Grade, in. per ft. | Dry tons per 24 hr. |
|-------------------------------------------------|----------|-----------------------|------------------------|--------------------|---------------------|
| 4 mesh from batteries.....                      | 4:1      | 8                     | 8                      | 1¾                 | 255                 |
| 12 mesh from batteries.....                     | 6.5:1    | 8                     | 8                      | ¾                  | 200                 |
| —4 mesh from Chileans.....                      | 3.3:1    | 8                     | 8                      | 1½                 | 400                 |
| —30 mesh from Chileans.....                     | 3.3:1    | 8                     | 8                      | ¾                  | 400                 |
| Tube-mill discharge 50 per cent. —200 mesh..... | 1.5:1    | 6                     | 5                      | 1¾                 | 100                 |
| Mixture of tube-mill and Chilean products.....  | 2.6:1    | 8                     | 8                      | ¾                  | 700                 |
| Mixture of tube-mill and Chilean products.....  | 2.1:1    | 6                     | 5                      | 1½                 | 200                 |
| Final product from tube mills....               | 3:1      | 5½                    | 8                      | ¾                  | 330                 |
| Product from Callow tanks.....                  | 3:1      | 3½                    | 3½                     | ⅞                  | 22                  |
| Concentrate.....                                | 9:1      | 3                     | 3                      | 1⅛                 | 35                  |
| Middling.....                                   | 3:1      | 3                     | 3                      | ¾                  | 10                  |
| Tailing.....                                    | 5:1      | 5                     | 5                      | ¾                  | 52½                 |
| Concentrate.....                                | 9:1      | 4                     | 10                     | ¾                  | 50                  |
| Tailing.....                                    | 5:1      | 10½                   | 10½                    | ¾                  | 800                 |
| Water.....                                      | .....    | 18                    | 14                     | ⅛                  | .....               |



TABLE LXXXVI.—LAUNDER DATA: CANANEA CONSOLIDATED COPPER COMPANY<sup>75</sup>

| Material handled                                           | Size of<br>launder, inches,<br>depth width | Grade,<br>in per<br>ft. | Lining                            | Ratio<br>solids;<br>liquids | Largest<br>particle,<br>mm. | Per<br>cent.<br>wt.<br>on 60<br>mesh |
|------------------------------------------------------------|--------------------------------------------|-------------------------|-----------------------------------|-----------------------------|-----------------------------|--------------------------------------|
| Original feed, to Section "C"                              |                                            |                         |                                   |                             |                             |                                      |
| Bull jig tails, to coarse rolls                            | 10 X 12                                    | 3½                      | C.I.—11½"                         | 1:1                         | 30.0                        | 82.0                                 |
| Roll jig tails, to fine rolls                              | 10 X 9½                                    | 3                       | C.I.—9½"                          | 1:1.1                       | 28.0                        | 98.0                                 |
| Coarse jig concentrates                                    | 10 X 7½                                    | 2½                      | C.I.—7½"                          | 1:3                         | 10.0                        | 98.0                                 |
| Undersize 2 mm. trommel to classifier                      | 10 X 5½                                    | 1½                      | C.I.—5½"                          | 1:2.9                       | 35.0                        | 95.0*                                |
| First spigot of classifier to sand jig                     | 8 X 5½                                     | 1½                      | C.I.—5½"                          | 1:4.4                       | 4.0                         | 52.0*                                |
| Shaking launder <sup>1</sup> for sand jig concentrates     | 8 X 5½                                     | 3½                      | C.I.—5½"                          | 1:1.5                       | 4.0                         | 90.0                                 |
| Fine jig concentrates from shaking launder                 | 6½ X 12                                    | 1½                      | None—corners                      | 1:19.0                      | 4.0                         | 94.0                                 |
| Bryan (Chile) mill discharge to drag belt                  | 10 X 7½                                    | 1½ <sup>16</sup>        | C.I.—7½"                          | 1:6.0                       | 4.0                         | 80.0                                 |
| Drag belt sands to classifier distributor                  | 8½ X 11½                                   | 2½                      | None—corners                      | 1:1.7                       | 2.5                         | 26.0                                 |
| No. 1 spigot of classifier to mud jigs                     | 10 X 7½                                    | 1½                      | C.I.—7½"                          | 1:0.9                       | 2.5                         | 46.0                                 |
| Table feed, tables 27 to 30                                | 8 X 5½                                     | 1½                      | C.I.—5½"                          | 1:17.0                      | 3.0                         | 60.0                                 |
| Table concentrates, drag belt launder <sup>2</sup>         | 7½ X 5½                                    | 2½                      | None—corners                      | 1:8.4                       | 1.0                         | 0.3                                  |
| Table concentrates, shaking launder <sup>3</sup>           | 9½ X 9½                                    | 2½                      | 1½" boards                        | 1:26.0                      | 1.0                         | 13.6                                 |
| Slimes, Section "C," settling tanks to Section "B" vanners | 4 X 7½                                     | 3½                      | None—corners                      | 1:7.4                       | 0.5                         | 35.2                                 |
| Slime feed to vanners, Section "C"                         | 6½ X 9½                                    | 9½                      | None                              | 1:96.0                      | 0.17                        | 0.0                                  |
| Vanner concentrates, drag belt launder <sup>4</sup>        | 9½ X 11½                                   | 1½                      | None                              | 1:4.7                       | 0.17                        | 0.5                                  |
| Vanner and table concentrates                              | 10 X 25 X 16                               | Level                   | None                              | 1:31.0                      | 0.2                         | 1.0                                  |
| Vanner tails, section "C"                                  | 6½ X 6                                     | 1½ <sup>16</sup>        | None                              | 1:20.0                      | 2.0                         | 27.2                                 |
| Coarse tails, table and jig                                | 9½ X 11½                                   | 1½                      | None—corners                      | 1:7.0                       | 0.4                         | 0.4                                  |
| Coarse sand tailings to dam No. 2                          | 9½ X 22                                    | 1½                      | 1½" boards & corners <sup>5</sup> | 1:97.0                      | 2.0                         | 41.6*                                |
| Coarse sand tailings to dam No. 1                          | 12½ X 11½                                  | 1½ <sup>16</sup>        | 1½" boards & corners <sup>5</sup> | 1:21.0                      | 2.0                         | 19.5*                                |
| Slimes to mill No. 4                                       | 12 X 11                                    | 3½                      | 1½" boards & corners <sup>5</sup> | 1:21.0                      | 2.0                         | 19.6*                                |
| Sands and slimes to mill No. 3                             | 9½ X 12½                                   | 3½                      | None—corners                      | 1:4.4                       | 0.1                         | 0.0                                  |
| Feed to vanners, mill No. 4                                | 10 X 11½                                   | 3½                      | None—corners                      | 1:5.0                       | 1.5                         | 2.6                                  |
| Slime concentrates, mill No. 4, drag belt launder          | 6 X 7½                                     | 3½                      | None                              | 1:4.4                       | 0.1                         | 0.0                                  |
| Slime concentrates, mill No. 4, elevator to bins           | 12 X 24 X 18                               | Level                   | None <sup>6</sup>                 | 1:20.0                      | 0.1                         | 0.2                                  |
| Slime concentrates, mill No. 3, elevator to bins           | 7 X 12                                     | 3½                      | Glass—corners <sup>7</sup>        | 1:8.7                       | 0.1                         | 0.4                                  |
| Slime tails, mill No. 4, to mill No. 3 settling tanks      | 10 X 11                                    | 1½ <sup>16</sup>        | Concrete                          | 1:6.3                       | 0.2                         | 2.8                                  |
|                                                            |                                            | 3½                      | None—corners                      | 1:6.3                       | 0.1                         | 0.0                                  |

All cast-iron liners have 2-in effective depth and 24-in. length, with corners rounded.

<sup>1</sup> Liable to choke. <sup>2</sup> Speed 160 r.p.m., actuated by heavy head motion. "Corners" are strips of wood with cross-section of 45° triangle nailed in corners of launder. <sup>3</sup> Speed 75 ft. per min.; old 4-in. drive belts are used, no scrapers. <sup>4</sup> Frequency 180 s.p.m.

<sup>5</sup> Effective width, 6 in. <sup>6</sup> Speed 75 ft. per min. <sup>7</sup> Boards laid with grain across direction of flow. <sup>8</sup> Glass liners, ¾ X 4 X 14 in

TABLE LXXXVII.—PULP TRANSFERENCE IN PIPING AT THE HOMESTAKE MILL<sup>\*1</sup>

| Sand line at Lead                          | Central City tailing line                                                                                                                               | Slime line at Lead |                 |
|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|-----------------|
| Diameter of pipe, in.....                  | 12                                                                                                                                                      | 8                  | 12              |
| Thickness of pipe, in.....                 | $\frac{9}{16}$                                                                                                                                          | $\frac{9}{16}$     | $\frac{9}{16}$  |
| Average grade, per cent.....               | $2\frac{1}{2}$ to 5                                                                                                                                     | $1\frac{3}{4}$     | $1\frac{1}{2}$  |
| Bends in line.....                         | The pipes generally follow the contour of the hills: the sharpest curve is $22\frac{1}{2}$ deg., a standard elbow for flanged C. I. piping being used   |                    |                 |
| Fineness of tailing in pulp, per cent..... | 30+100                                                                                                                                                  | 25+100             | 100-200         |
|                                            | 25+200                                                                                                                                                  | 20+200             |                 |
|                                            | 45-200                                                                                                                                                  | 55-200             |                 |
| Water in pulp, per cent.....               | 70-75                                                                                                                                                   | 85-90              | 65-70           |
| Solids per 24 hr., tons.....               | 1950                                                                                                                                                    | 450                | 1100            |
| Pipe runs.....                             | About $\frac{1}{3}$ full                                                                                                                                | Full               |                 |
| Wear.....                                  | It is customary to turn pipe through about 120 deg. when bottom is worn thin; thus the pipe will be used until three lines of wear have been developed. |                    |                 |
|                                            | On 5 per cent. grade worn out in 2 years.                                                                                                               | In use 8 years     | In use 5 years  |
|                                            | On $2\frac{1}{2}$ per cent. grade worn from 9-10 years.                                                                                                 | without turning    | without turning |
|                                            | Most of line still in use after 11 years, but badly worn.*                                                                                              |                    |                 |

\* Remarks: The grade has been reduced to  $2\frac{1}{2}$  per cent. throughout and new piping 1 in. thick has been installed.

## SECTION XIV

### CLASSIFICATION OF ORE PULP

**Classification of Ore Pulp** is a process relying on specific gravity differences in the ground material, the settlement resistance factor between products having different physical characteristics, and the fluidity of the vehicle in which the ore is temporarily suspended. Colloids in suspension generally interfere with classification results by increasing the viscosity of the liquid.

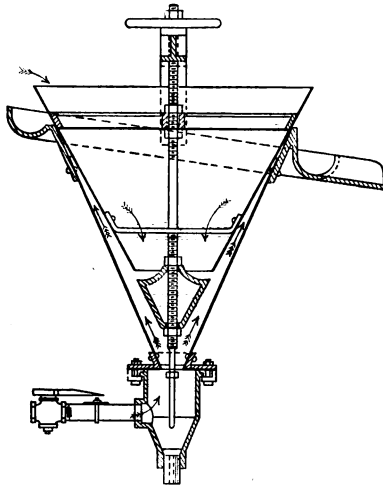


FIG. 136.—Hydraulic classifier.

**Classifiers** may be divided into two kinds, viz.: the gravitational and the mechanical. In the former class there are numerous designs of the conical or pyramidal form, some of which make use of hydraulic water for the better separation of material of different grades (see Fig. 136) and all relying on the flow of

water carrying the ore to retain the finer particles in suspension. Cone classifiers may be operated "dry" (*i.e.*, with low moisture percentage in underflow), as in the case where a deposit is allowed to accumulate and remain in the cone before any underflow is tapped; or they may be operated "wet" with varying percentages of water in the underflow. Cones running "dry" are usually fitted with a baffle plate near the apex. The function

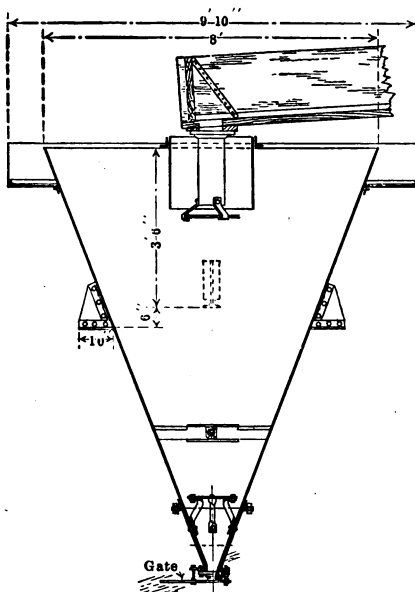


FIG. 137.—Caldecott cone.

of this is to prevent "running" of the entire contents of the cone by "piping" through the center. The Caldecott cone (Fig. 137) is of this type.

The **Allen Cone** is an apparatus of the Caldecott type which is provided with automatic control of underflow. The pulp stream enters the feed spout *A* (see Fig. 138) and, after passing through the truncated cone *B*, the bulk of the water and finer material flows upward and into the overflow launder. The sand

particles settle in the cone and form the basin. When the settled sand reaches the outlet of *B* it obstructs it, so that the water rises in *B*. This lifts the float *C*, thereby removing the ball *G* from the spigot by means of the lever *D*, the link *E*, and

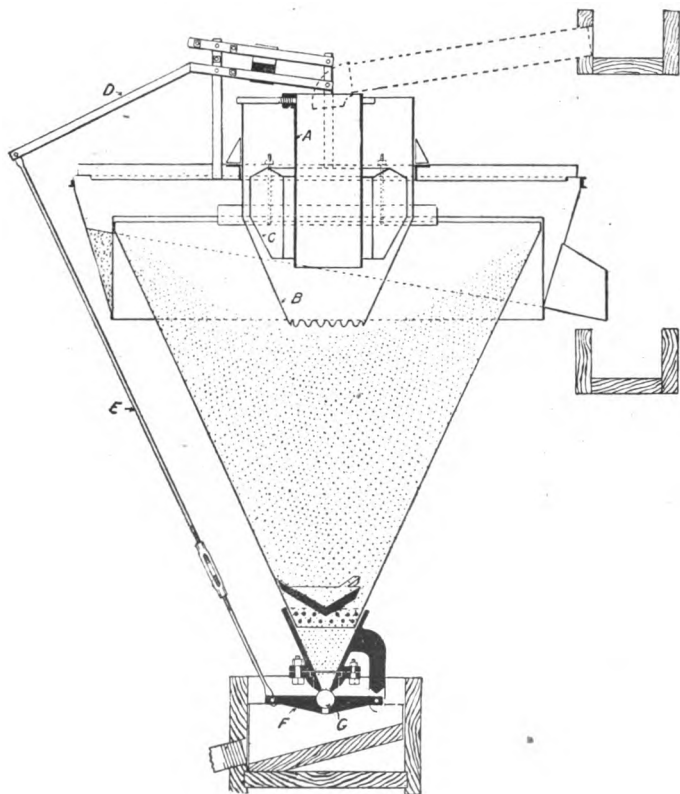


FIG. 138.—The Allen cone.<sup>77</sup>

the valve arm *F*. The settled solids flow out in a continuous stream, the quantity discharged being controlled by the quantity settling in the cone. When sand ceases to enter the cone *B* the ball *G* closes the spigot, and it remains closed until the feed of sand is renewed. The automatic operation of this apparatus

should make it of especial value in those cases where dewatering or classifying by cone has been proved to be cheap and comparatively efficient.

**Cone Classifiers of the Multiple Type** (Fig. 139) produce more than two products, and similar results may be obtained by using single cones in series. Dimensions of cone parts, and the degree of inclination of the sides are matters depending on character of feed, character of product required, and tonnage to be handled, and are influenced by the physical properties of the ground material. Classification in cones is being carried out under an almost infinite variety of conditions as to design, and no general rules can be enunciated.

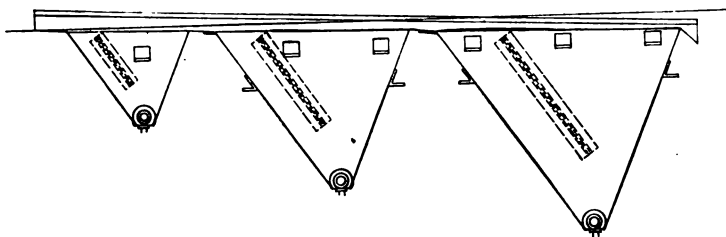


FIG. 139.—Multiple cone classifiers.

**Homestake Cone Practice** (Fig. 140) represents an unusual arrangement notable for the results obtained and the small amount of attention required. The first section of the installation consists of 14 gravity cones, 4 ft. in diam., with a 70-deg. slope. The usual overflow arrangements are provided, but the underflows are each supplied with a high-pressure emergency water supply, as illustrated, and are each connected by a length of steam hose to a second cone of 16-in. diam. and 80-deg. slope. The latter series of cones are supplied with extra water in the manner shown, and the sand feed is delivered in an upward direction from the lower part of the cone near the apex. The overflow arrangements are as usual, and the underflow passes direct to the tube mill, being diluted with low-pressure water as found necessary.

**Spitzluten** are pointed boxes with an ascending current of water to assist classification. An apex discharge is arranged for the coarse product and an overflow, either around the

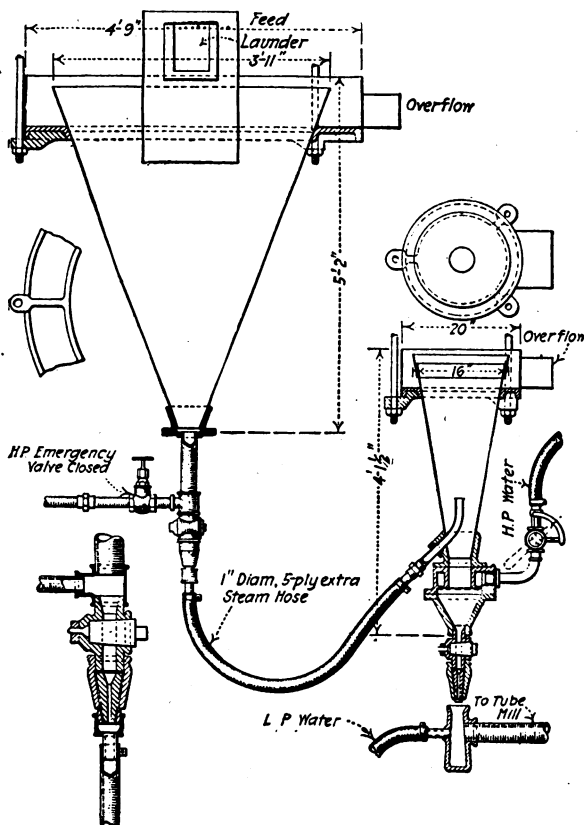


FIG. 140.—Homestake cone practice.<sup>51</sup>

whole or part of the top periphery, carries with it the finer material.

**Spitzkasten** are similar to spitzluten but without the ascending current of water. Types are illustrated in Fig. 141.

**Porcelain or Glass Nozzles** have been used in some mills in the regulation of cone classifier discharge underflow and have been found to outlast steel bushings.



FIG. 141.—Types of compound spitzkasten.

In the **Flood Classifier** (Fig. 142) the upward current of water is applied through the medium of a centrally located pipe and is distributed from three tiers. Coarse material is subjected

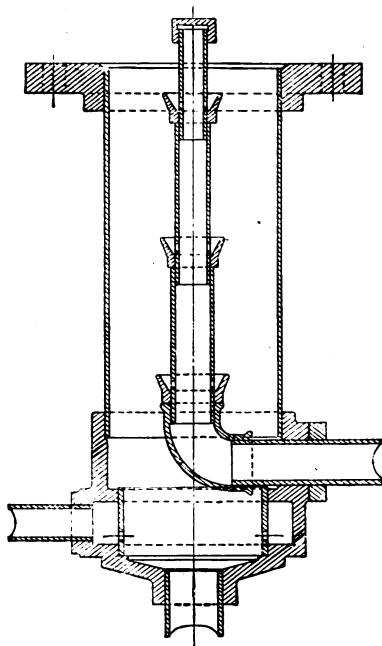


FIG. 142.—Flood classifier.<sup>19</sup>

to the influence of the currents produced during its passage from intake to exit, and fines are separated from coarse material during the process. The classifier may be attached to the bottom



of a launder carrying pulp, or may be fitted with a box top. It may be used singly or in series.

The **Deister Classifier** (Fig. 143) consists of a cast-iron barrel carrying inverted truncated cones arranged with slots of a size permitting the free passage of the coarser material. The pulp

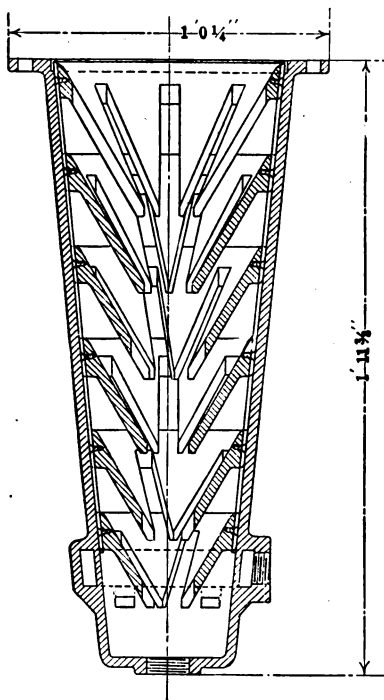


FIG. 143.—Deister cone classifier.<sup>78</sup>

route through these cone slots is staggered, the openings from one cone being out of line, vertically considered, with the adjacent cones. Hydraulic water is admitted through one of the side inlets in the annular waterway underneath the bottom. These cones may be used singly or in series, and their introduction has marked a decided advance in the practice of cone classification.

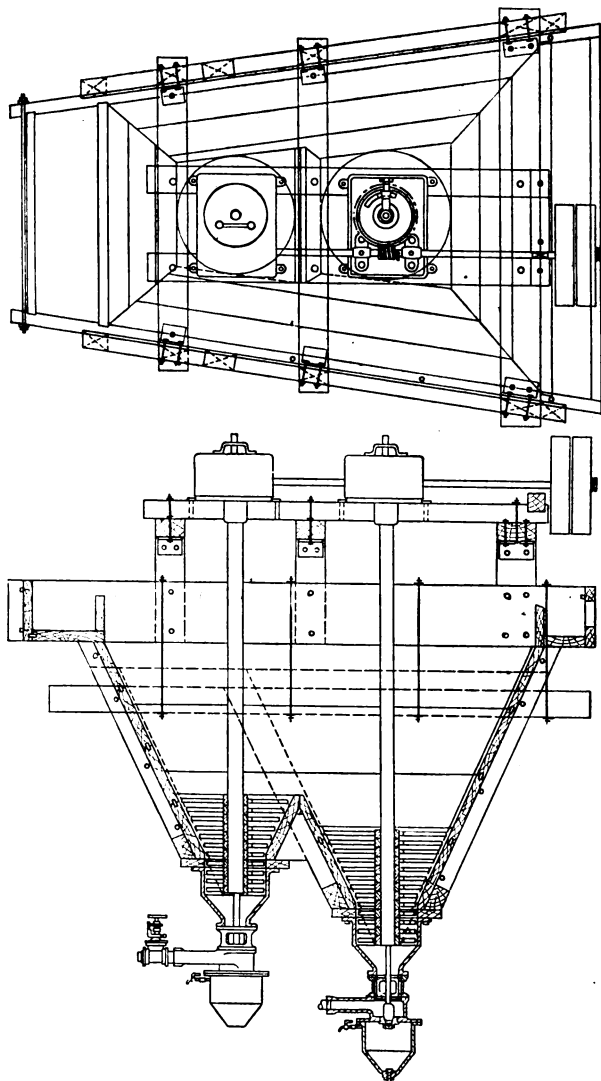


FIG. 144.—Richards-Janney classifier (2 compartment).<sup>11</sup>

The **Richards-Janney Classifier** consists of a series of rectangular compartments in the form illustrated in Fig. 144. In the cone apex a cylindrical settling chamber is arranged which is connected, lower down, with a hydraulic water supply.

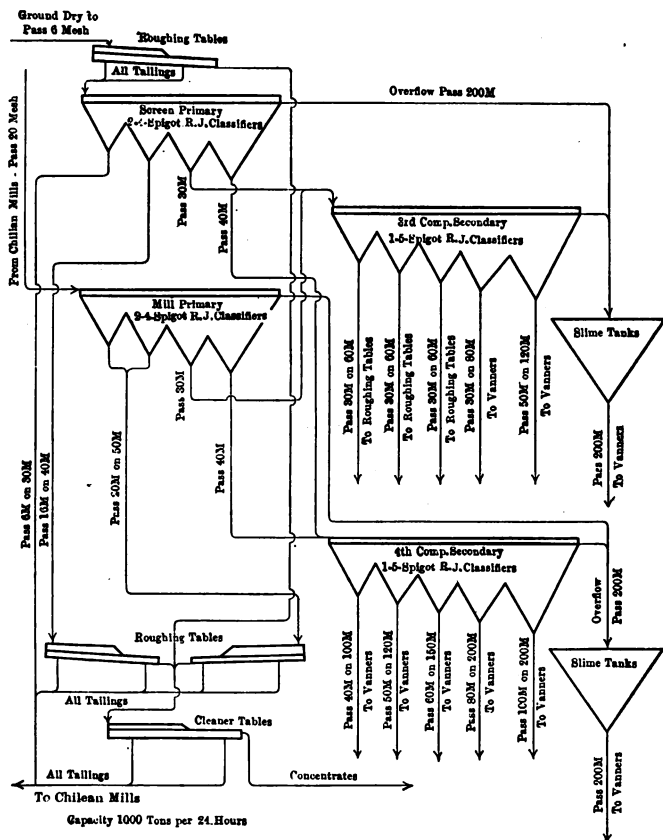


FIG. 145.—Richards-Janney classification practice at the Magna plant of the Utah Copper Company.

A worm shaft, attached to the upper framing, operates at from 80 to 90 r.p.m.; and, by the movement of a shaft connected to a series of sifting blades at the bottom of the chamber, the pulp

is loosened. A valve rod which passes through the spindle shaft, which is hollow, is raised intermittently by cam action, and an amount of material is thus permitted to pass to the hydraulic chamber. On the dropping of the valve rod the classified material passes out and the chamber is then ready for an additional charge.

**Richards-Janney Classification** at the Magna plant of the Utah Copper Company, Garfield, Utah, is illustrated by flow-sheet (Fig. 145) showing arrangement of classifiers in the mill, accompanied by a statement of comparative results in Table LXXXVIII.

TABLE LXXXVIII.—COMPARATIVE RESULTS OF OPERATION OF RICHARDS-JANNEY CLASSIFIERS

| Classifier                        | Tons handled | Max. mesh | Size bushings, in. | Gal. water entering per ton | Gal. water injected per ton | Gal. water discharged per ton | Gal. water over-flow per ton | Total gal. per ton |
|-----------------------------------|--------------|-----------|--------------------|-----------------------------|-----------------------------|-------------------------------|------------------------------|--------------------|
| Screen primary.....               | 450          | 6         | 1½, 1½<br>1, 1     | 225                         | 364                         | 361                           | 228                          | 589                |
| Mill primary.....                 | 757          | 20        | 1¼, 1<br>1, 1¼     | 361                         | 160                         | 189                           | 314                          | 503                |
| Third compartment secondary.....  | 233          | 30        | ¾, ¾,<br>¾, ¾, ¾   | 824                         | 470                         | 359                           | 964                          | 1323               |
| Fourth compartment secondary..... | 310          | 40        | ¾, ¾,<br>¾, ¾, 1   | 506                         | 486                         | 463                           | 529                          | 992                |

NOTE.—The small amount of water injected per ton and discharged per ton in results obtained from mill primary classifier is due to heavy circulation from first and second spigots. See flow sheet (Fig. 145), upon which above data are based.

The launder-type **Richards Pulsator Classifier** consists of a settling pocket which may be attached directly to the bottom of a launder in the manner shown in Fig. 146. Below the settling pocket is a sorting column that receives water by means of a pulsator valve in an upward direction. A spigot discharge is arranged.

In the inverted type **Richards Pulsator Classifier** shown in Fig. 147 the finest material is delivered from the first compartment. Hydraulic water is pulsated into the machine, passes through a separating screen, and through the outlets which are placed only slightly below the level of the feed intake. The various compartments, from the first onward, decrease in cross-section, and as the hydraulic water is distributed under even pressure, the velocity of ascending water in any compartment will vary inversely as its cross-section, being at a minimum in the first compartment and at a maximum in the last compartment. The screen serves to support the ore bed and distribute the water supply evenly. Hydraulic water supply may be adjusted so that all solid particles pass through the discharge spigots; or the spigot just above the screen in the last compartment may be used as an outlet for concentrate.

The **Overstrom Classifier** (Fig. 148) operates somewhat similarly to the Richards Pulsator Classifier and discharges the products at the top of the machine. Referring to the accompanying cut it will be seen that the feed enters at A, passes a screen and enters the first compartment, which is sup-

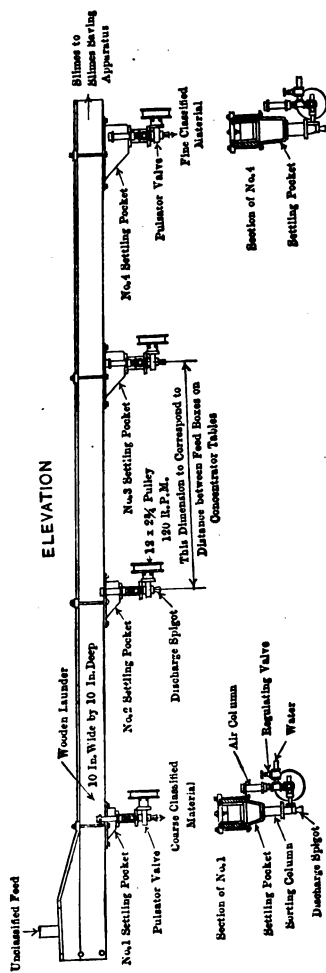


FIG. 146.—Launder-type Richards pulsator classifier.<sup>16</sup>

plied with hydraulic water as shown. The slime overflows, and the sand then drops through a slot into the first sorting column. The heavier material drops through *G* and passes to the next compartment, and so on.

In the **Richards Hindered-Settling Classifier** (Figs. 149 and 150) the sorting is effected by permitting the articles to aggre-

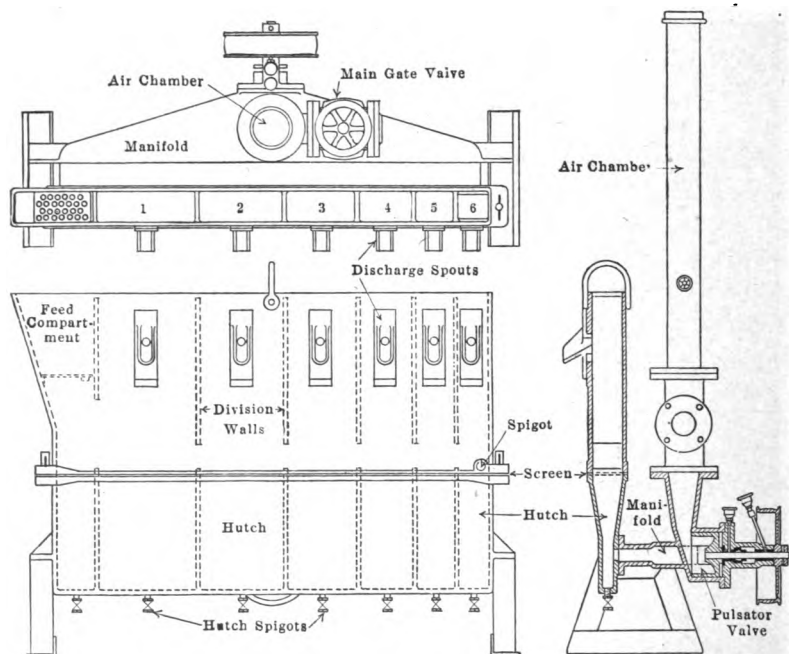


FIG. 147.—Richards pulsator classifier (inverted type).<sup>16</sup>

gate in a constriction formed in the lower part of the sorting column, where they are subjected to the separating effect of an upward current of water.

**Concentrating Tables** may in certain instances be used as classifiers. The Wilfley table has been extensively used in this respect without any interference with its concentrating functions. A clear line of demarcation between sand and slime zones at the

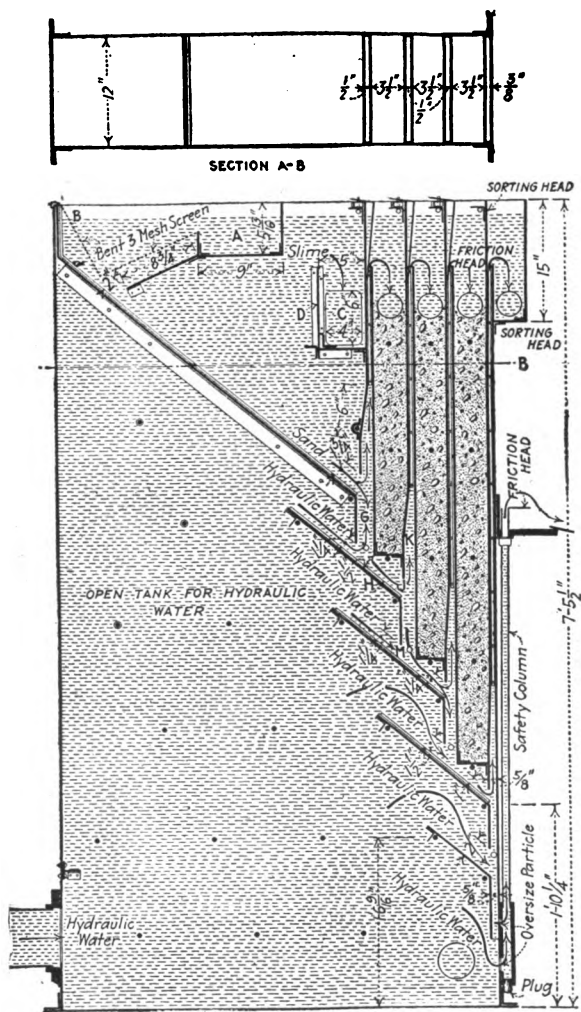


FIG. 148.—Section of Overstrom classifier.<sup>79</sup>

table discharge is generally observable, and advantage is taken of this by dividing the tailing launder and equipping this with an adjustable divider to allow for tonnage fluctuations or variations in the character of the ore.

The **Dorr Classifier** (Fig. 151A) consists of a longitudinal trough with inclined bottom and vertical sides, in which numbers of mechanically operated scrapers serve to drag the coarser material toward the upper end of the trough and expose it to a washing action in so doing. The action of the scrapers is inter-

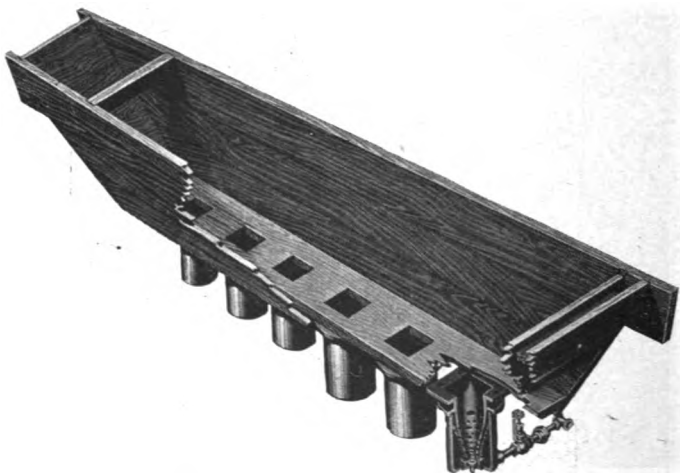


FIG. 149.—The Richards hindered-settling classifier.<sup>11</sup>

mittent and the operation is governed by an arrangement of cams, levers, rods, and cranks, a combination that produces a slow raking motion. A modification of the standard machine—the bowl-type classifier—has a classifying chamber (see Fig. 151B) connected to the classifier tank compartment. The feed is delivered to the center of the bowl, the bottom of which is swept by a mechanism similar to that used in the **Dorr thickener**. The settled solids are delivered through an orifice to the classifier proper, where the sand is handled in the usual way. Water is



added in the tank compartment. This insures a rising current through the orifice and assists efficient separation.

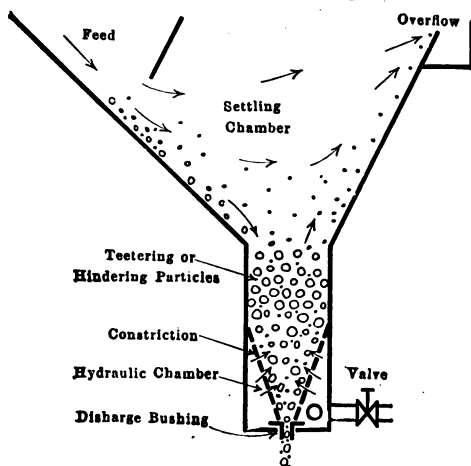


FIG. 150.—Operation of Richards hindered-settling classifier.<sup>11</sup>

The **Akins Classifier** (Fig. 152) operates on the principle of the ribbon conveyor with a large-diameter spiral that prevents

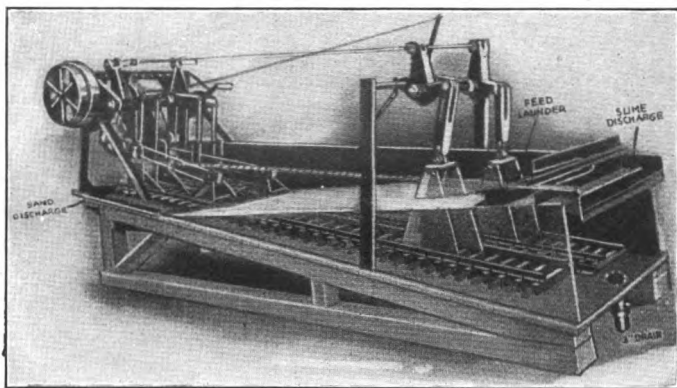
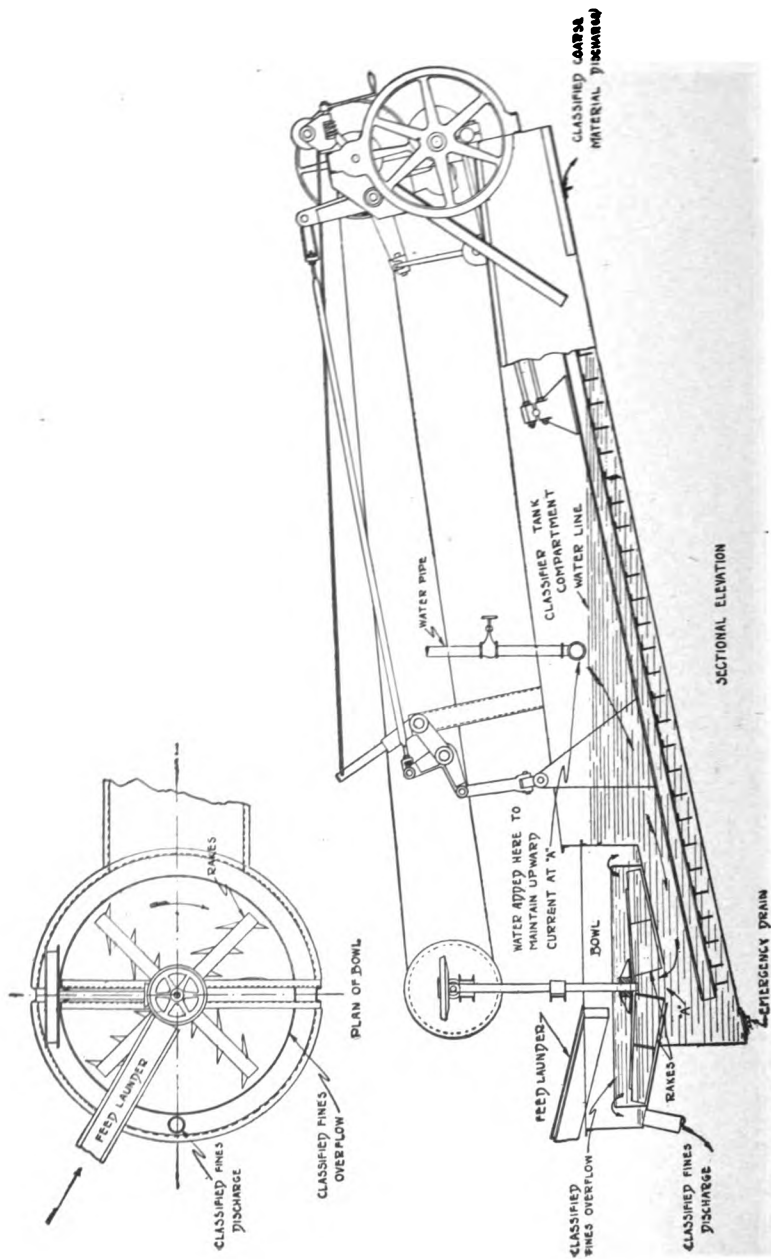


FIG. 151A.—Dorr classifier.<sup>80</sup>

the building up of solids in any part of the apparatus. The helix is continuous for a part of the length commencing from the over-

FIG. 151B.—Dorr bowl-type classifier.<sup>80</sup>

flow end, then double and interrupted. This aids in the elimination of moisture in the sand product and assists, by continually turning over the material, in the separation of the required products. The operation of this type of classifier in closed circuit

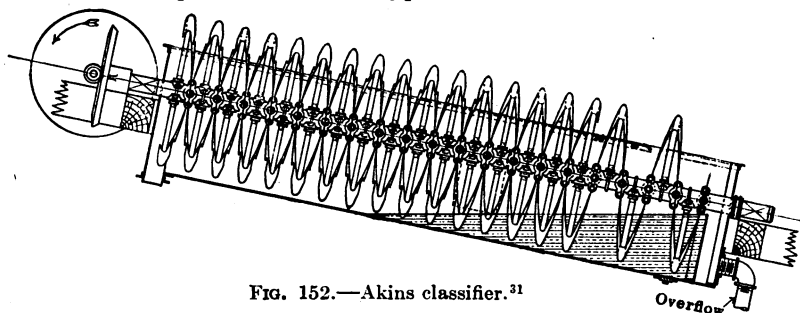


FIG. 152.—Akins classifier.<sup>31</sup>

with a ball mill, and in connection with which no elevating return system is necessary, is shown in Fig. 153.

The **Ovoca Classifier** (Fig. 154) works on the principle of the screw conveyor. The smaller types are fitted with one screw only, whereas the larger ones operate with two screws. The set-

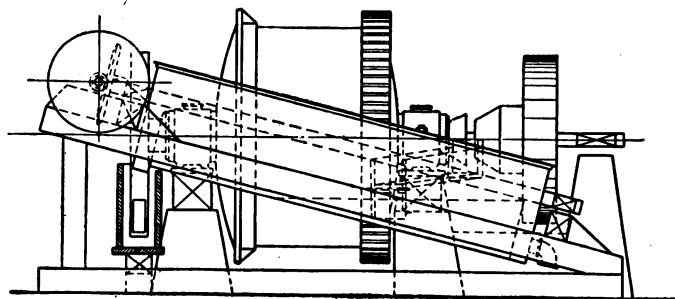


FIG. 153.—Akins classifier in closed circuit with ball mill.<sup>31</sup>

tled ore is withdrawn from a small tank by means of the conveyor and delivered above the classifier intake level. The finer material overflows around an annular discharge attached to the tank.

The **Federal Esperanza Classifier** consists of a series of scrapers attached to a belt which remove and elevate the settled material from the floor of a trough with inclined bottom.

The **Drag Classifier** used at the **Inspiration** mill handles 800 tons per day and consists of two 18-in. belts with scrapers attached. The returning belt is raised to a point above the level of the pulp by means of a duplication of the pulley at the feed end, a second pulley being placed vertically above the other.

**Classifier Efficiency** is seldom determined, owing to the prevalent opinion that the work of the machine may be gauged from a statement of grading analyses of feed and discharge. As a matter of fact such figures are always valueless and sometimes mis-

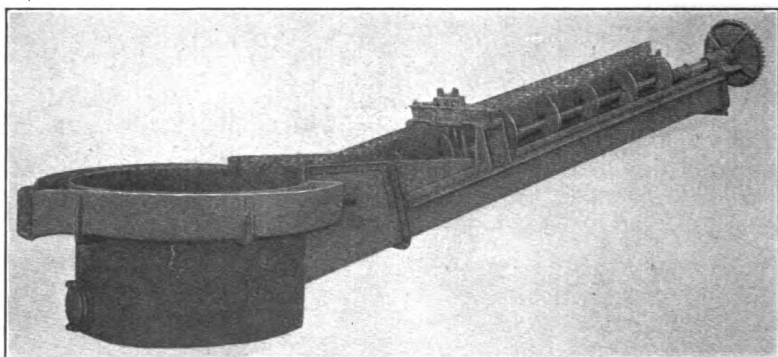


FIG. 154.—Single-screw Ovoca classifier.<sup>16</sup>

leading except when used in conjunction with tonnage of feed and individual discharge. With simple classifiers the efficiency of classification at a certain mesh, dividing an undersize from an oversize, may be found from the following formula:

$$\frac{100(t + t')}{F} = \text{efficiency of classification,}$$

where  $t$  = tonnage of oversize in the coarse product, and  $t'$  = tonnage of undersize in the fine product, and  $F$  = total feed tonnage, all per unit of time. An example is given in Table LXXXIX.

**Compound-Classifier Efficiency** may be estimated in a similar way by extending the formula thus:

$$\frac{100(t + t' + t'' \dots + 0)}{F} = \text{efficiency of classification,}$$

where  $t$  = tonnage of required grading in first product,  $t'$  = tonnage of required grading in second product, etc., and  $0$  = tonnage of required undersize in overflow, and  $F$  = total tonnage in feed.

TABLE LXXXIX.—CLASSIFIER EFFICIENCY

Plant: Inspiration Consolidated Copper Co.

Classifier: Model D Dorr,  $6 \times 27$  ft.

Speed: 25 strokes per min.

Slope:  $2\frac{5}{8}$  in. to 1 ft.

Tonnage feed: 1100

Tonnage coarse product discharge: 790

Tonnage fine product discharge: 310

Separation desired: 65 mesh

| Screening analysis |                                        |                                      |
|--------------------|----------------------------------------|--------------------------------------|
| Mesh               | Coarse-product discharge,<br>per cent. | Fine-product discharge,<br>per cent. |
| + 28               | 32.2                                   |                                      |
| - 28 + 48          | 39.6                                   | 0.6                                  |
| - 48 + 65          | 13.1                                   | 5.2                                  |
|                    | 84.9                                   | 5.8                                  |
| - 65 + 100         | 6.6                                    |                                      |
| - 100 + 150        | 2.9                                    |                                      |
| - 150 + 200        | 1.3                                    |                                      |
| - 200              | 4.3                                    |                                      |
|                    | 15.1                                   | 94.2                                 |
|                    | 100.0                                  | 100.0                                |

Classification efficiency: 84.9 per cent. of 790 tons =  $t$

94.2 per cent. of 310 tons =  $t'$

= 962.73 tons of a possible 1100 = 87.5 per cent. efficiency.

The **Elimination of Oversize from Overflow** is sometimes of prime importance. In other cases the inclusion of fines in the underflow is to be avoided. In either case the simple method of calculating classifier efficiency outlined will, if utilized, serve to assist adjustment and produce the most satisfactory results possible.

## SECTION XV

### THICKENING, SETTLING, AND DEWATERING OF ORE PULP

**Settlement and Thickening of Ore Pulp** are generally synonymous phrases. Apparatus used may be considered under two headings, viz.: the gravitational, and the gravitational-plus-mechanical. Among gravitational settlers may be mentioned the conical and spitzkasten types, or simple sloping-bottomed vats. The gravitational-plus-mechanical types have an arrangement whereby discharge is assisted and regulated by mechanical means, with either an intermittent or continuous action.

**Gravitational-Thickening Efficiency** is governed by various factors, among which may be mentioned, (a) dilution of pulp feed, (b) condition of colloidal constituents with reference to electrolytic coagulation, (c) area of settlers, and (d) depth of settlers. Assuming maximum favorable comparative conditions in these respects, the actual degree of thickening attained with a fine product will be proportional to the time allowed. Where maximum dewatering is required the intermittent gravitational-plus-mechanical type of settler will give a product freer from water than the continuous machine. The advantages of ample allowance in the time factor for slime settlement may be utilized without direct mechanical aid, as in the case where the settled contents of large sloping-bottomed vats are sluiced out with the cyanide solution needed for subsequent recovery treatment. Intermittent gravitational thickening is only feasible in large-capacity vats.

The **Pulp Thickener** illustrated in Fig. 155 is of the intermittent type and is operated in series. As soon as filled with slime, *i.e.*, when the overflow is no longer clear, the pulp stream is

diverted. The pulp in the vat is allowed to thicken to any desired extent and the clear water decanted off. An agitator paddle, at the end of a square vertical shaft and driven by a crown-wheel gearing through which the shaft is free to move in a vertical direction, is then slowly lowered into the pulp,

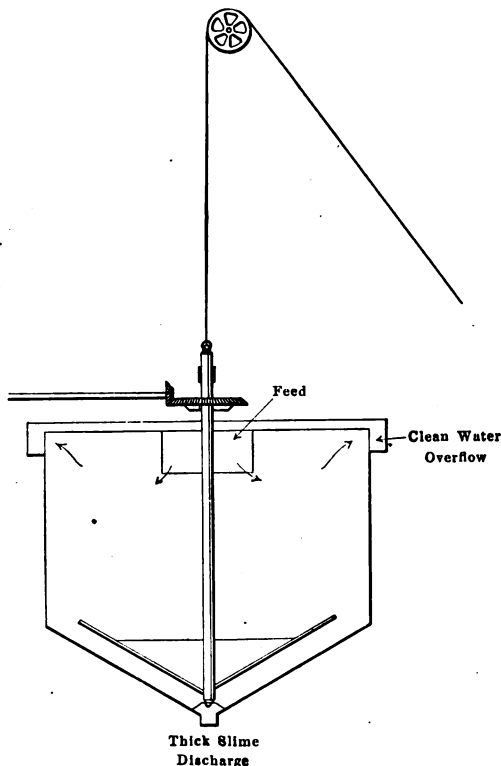


FIG. 155.—Pulp thickener.

revolving the while at about 20 r.p.m., until a few inches from the bottom. After a few moments the contents of the vat are thoroughly mixed and the thick sludge may be drawn off through an appropriate discharge valve attached to the cone at the bottom of the vat,

The **Dorr Continuous Thickener** (Fig. 156) consists of four radial arms attached to a central vertical shaft, suspended in a flat-bottomed tank in the manner shown, and revolved by means of worm gearing at a slow speed. The ploughs scrape the settled slime toward the center of the tank, where it is discharged or conveyed elsewhere. The discharge is preferably handled by means of a diaphragm pump, as shown in the

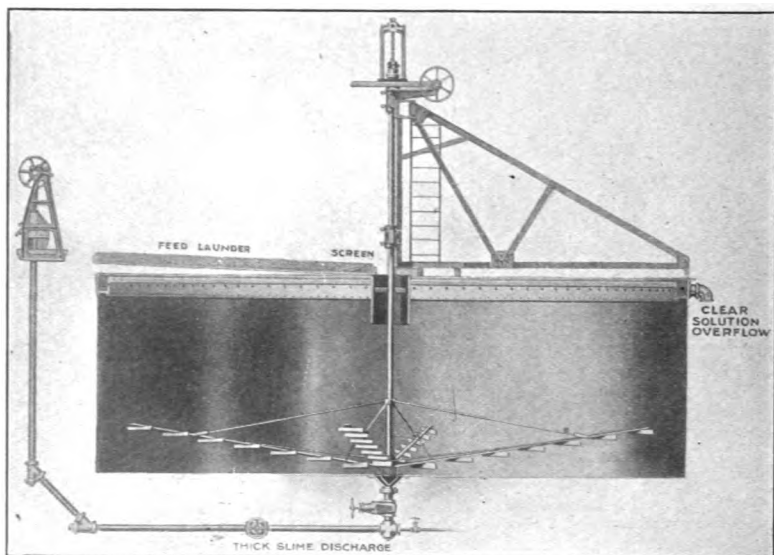


FIG. 156.—Dorr continuous thickener.<sup>80</sup>

cut, whereby loss of fall is avoided and improved results are insured. Details of typical practice are given in Table XC.

The **Dorr Tray Thickener** is an adaptation of the standard machine whereby increased settling area is obtained by means of a division or divisions of the tank into horizontal compartments, each fitted with a bottom tray conforming to the slope of the additional plough mechanism, which is a duplicate of that found in the ordinary machine. Two types are now in operation.



The **Open-Type** thickener is shown in Fig. 157. The **Connected-Type** thickener is arranged for the separate delivery of feed to each section, and the individual discharge of thickened products.

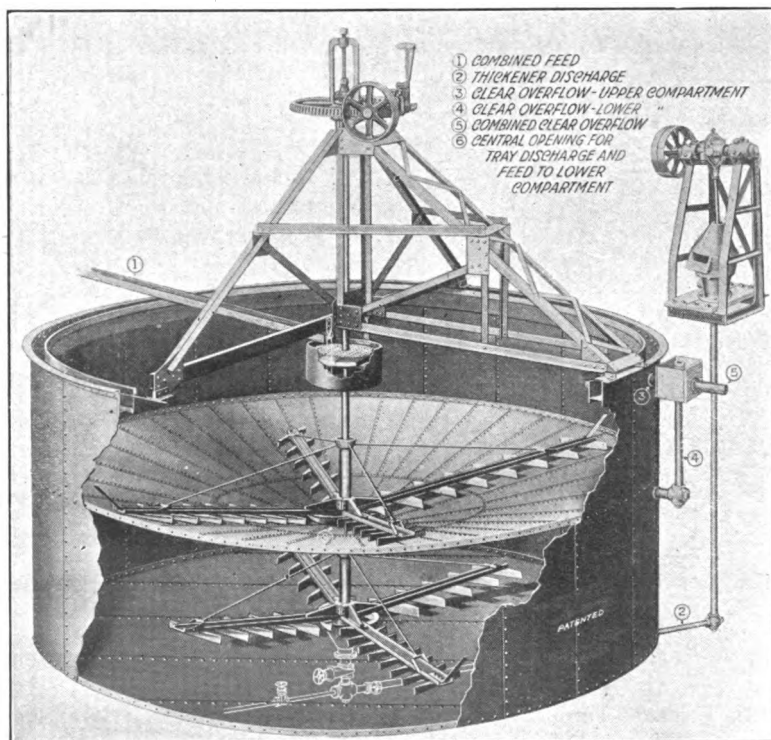


FIG. 157.—Dorr tray thickener—open type.<sup>80</sup>

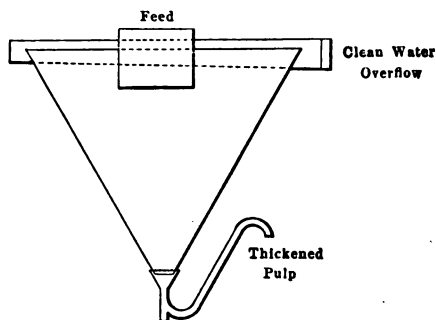
**Conical Settlers** (Fig. 158) are usually operated in parallel, as their capacity is small. Feed is delivered centrally, and the velocity of discharge of the thickened pulp may be lessened and fall required reduced by the use of a gooseneck discharge. Thickened pulp flow may be adjusted by means of a Bunsen valve operating on a piece of rubber tubing connecting any two convenient points in the gooseneck; or by means of the regulator

TABLE XC.—TYPICAL DORR THICKENER PRACTICE<sup>80</sup>

| Mill                               | Sq. ft. settling area per ton solids thickened in 24 hr. | Remarks                                                                                                                                                    |
|------------------------------------|----------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| San Rafael, Pachuca, Mex....       | 4.5                                                      | Tube-mill product, 75 per cent. —200 mesh. Discharge, 45.5 per cent. solids.                                                                               |
| Liberty Bell, Telluride, Colo..    | 7.1                                                      | Tube-mill product, much light argillaceous slime. Discharge, 30 per cent. solids.                                                                          |
| Batopilas, Chihuahua, Mex...       | 0.6 to 0.9                                               | 40-mesh product; 90 per cent. passing 100 mesh.                                                                                                            |
| Zambona Dev. Co., Sonora, Mex..... | 3.1                                                      | Tube-mill product. Discharge 40 per cent. solids.                                                                                                          |
| Nova Scotia, Cobalt, Ont. ....     | 5.4                                                      | Tube-mill product, 88 per cent. —200 mesh, ore diabase. Discharge, 40 per cent. solids. Feed 6:1.                                                          |
| El Palmarito, Sinaloa, Mex...      | 4.5                                                      | Tube-mill product—pure quartzite, 97 per cent. —200 mesh. Feed 7:1. Discharge, 65–70 per cent. solids. (Continuous decantation.)                           |
| Amparo, Jalisco, Mex.....          | 4.9                                                      | Tube-mill product—siliceous—93.5 per cent. —200 mesh. Feed 24.5:1. Discharge, 23.5 per cent. solids—used to feed vanners.                                  |
| Veta Colorado, Parral, Mex...      | 5.0                                                      | Tube-mill product—rather argillaceous—71 per cent. —200 mesh. Feed 11:1. Discharge, 33 per cent. solids for agitator. Have settled to 65 per cent. solids. |

| Mill                                                        | Sq. ft. settling area per ton solids thickened in 24 hr. | Remarks                                                                                                                                                                                                                                                                                   |
|-------------------------------------------------------------|----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Pennsylvania Steel Co.,<br>Lebanon, Pa.....                 | 2.9                                                      | Thickening ahead of vanner concentration; pulp in water. Feed 2.8 per cent. solid. Discharge, 10.6 per cent. solids. Overflow, 0.4 per cent. solids—extremely fine—which does not interfere with using water again in mill.                                                               |
| Nevada Consolidated Copper Co., Ely, Nev.....               |                                                          | Each 17-ft. thickener supplies wash water for twenty Wilfley tables and occasionally a surplus for use as wash water on vanners, all without the necessity of pumping. One thickener (area 226 sq. ft.) has a greater capacity than twelve 8-ft. cones (combined area about 525 sq. ft.). |
| B. H. Proprietary, Block 10,<br>Broken Hill, Australia..... |                                                          | Dewatering slime from lead-zinc concentration mill—three 24' × 10' thickeners handle about 5000 tons of water per day, in which is contained some 50 tons of slime, giving a perfectly clear overflow and a thick slime discharge containing about 45 per cent. moisture.                 |

shown in Fig. 159, which may be made of  $\frac{5}{8}$ -in. round iron. In the case where an exceptionally steady flow of ore is received by each cone the regulation may be done by means of a reducer or nozzle attached to the end of the gooseneck.



SECTIONAL ELEVATION

FIG. 158.—Cone thickener with gooseneck discharge.

Metal **Valves** are generally unsuitable for regulating the under-flow from cones or spitzkasten. This is due to the fact that in throttling the discharge one or more sharp corners are formed

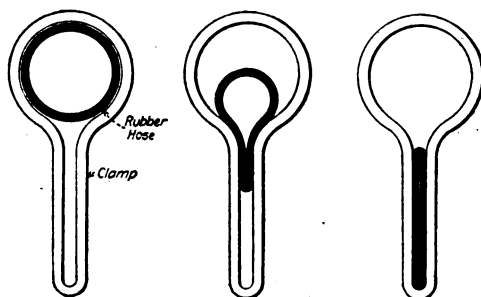


FIG. 159.—Hose discharge regulator.

which lead to an accumulation of solids and subsequent chokage of the cone. Stop-valves connected with the apices of cones should be of a type permitting no constriction in diameter

and should be left wide open during the operation of the cone.

**Spitzkasten Settlers** are usually operated in nests (Fig. 160). Angle of inclination of cone side depends on fall available and character of material to be thickened. Maximum possible slope is always advisable. With colloidal material there is a tendency

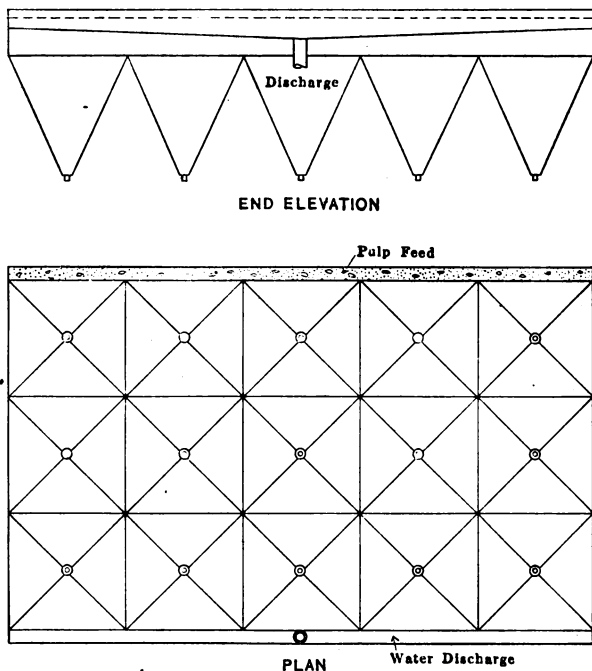


FIG. 160.—Spitzkasten settler.

for the slime to accumulate on the sides if the latter are insufficiently steep. This results in occasional chokage of the discharge. Goosenecks may be used in connection with spitzkasten settlers in the same way as with cones (*q.v.*).

**Prism Spitzkasten Settlers** are usually in series and are set transversely to the flow of pulp. An example of West Australian practice<sup>7</sup> shows the following dimensions:

Size, 111 ft. long by 42 ft. wide; number of prisms, 8; number of orifices in each prism, 30; distance between orifices, 3 ft. 8 in.; division plates between prisms, within 8 in. of surface of pulp; discharge, continuous from first row—intermittent from remainder; consistence of underflow, 1 to 1.

Details of design are shown in Fig. 161.

**Gravitation Thickening** may be carried out in any vat of suitable dimensions provided that the bottom slopes toward a point of discharge. If worked continuously there is an aggregation of solids in the bottom of the vat, and its capacity is rapidly reduced. By working intermittently and by sluicing out the accumulated slime by means of a high-pressure jet the apparatus may be operated at a fair efficiency.

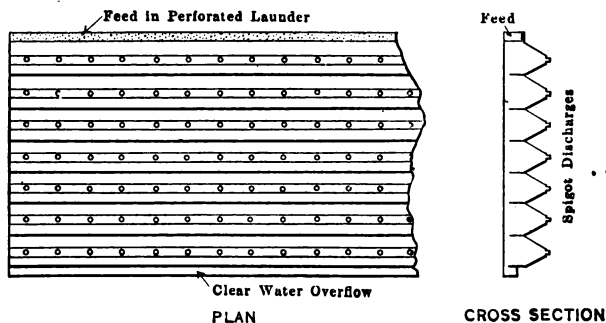


FIG. 161.—Prism spitzkasten settler.

The **Ayton intermittent Pulp Extractor**, for use with cones and pointed boxes, is a device consisting, in the main, of a valve the operation of which is controlled by a lever held in position by a spring and actuated by cam movement. The frequency and degree of opening of the valve are adjustable (see Fig. 162).

**Dewatering** is a term generally used in the case where it is possible to reduce the moisture percentage to a small amount, often as low as 5 per cent. This is effected directly by mechanical means, by pressure or vacuum involving filtration, and may be assisted by heat or compressed air.

**Mechanical Dewatering** of a **Sandy Product** may be effected in either of the mechanical-plus-gravitational classifiers previously described.

**Dewatering by Pressure** is effected by **Filter Presses** of the Dehne or Merrill types. In the former case the apparatus consists of a number of frames, usually about 4 ft. square and from 2 to 3 in. thick, separated by solid plates with channeled surfaces delivering to outlet ports at the bottom of each

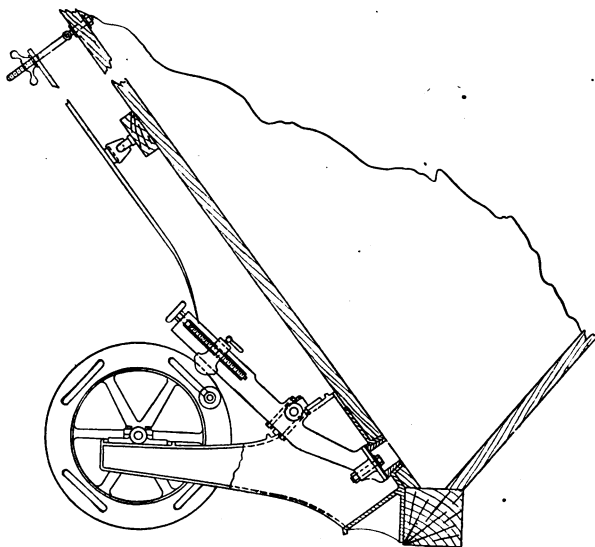


FIG. 162.—Ayton intermittent pulp extractor.<sup>11</sup>

plate. The latter are covered with suitable filter cloth, and the press is closed and the pressure joints are sealed by means of a hydraulic ram or pressure screws. Pulp is forced into the hollow frames by means of compressed air or pressure pump. When the frames are full and the cakes formed, the excess water may be removed by compressed air delivered through the filling port, or from alternate frames whose outlets have been temporarily closed. The press contents are discharged by releasing the pressure at the end, by drawing apart the frames and plates,

and by dumping the cakes of material into cars usually running on tracks below the press floor.

The **Merrill Filter Press** is only suitable as a dewaterer when subsequent treatment of the material can be effected by leaching in the press. The shape of the plate and frame is modified to allow for the introduction of a sluicing nozzle at the base of each frame, which rotates and automatically discharges the contents after treatment. Dewatering in this machine is only one phase

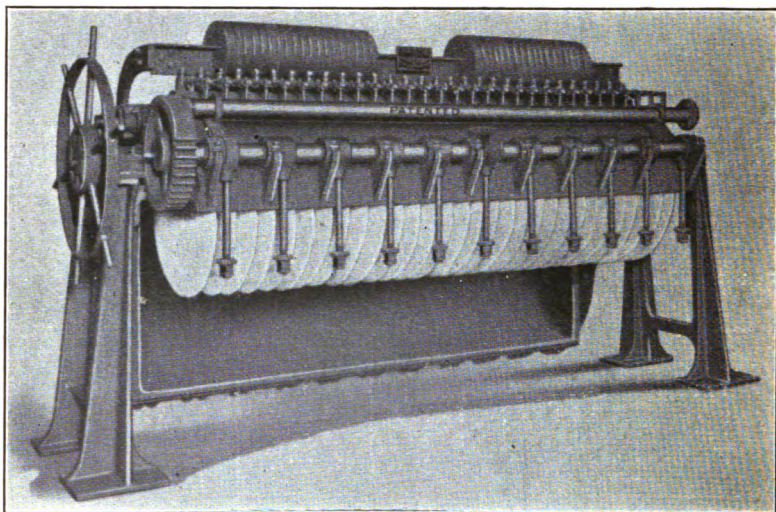


FIG. 163.—Sweetland filter press.<sup>82</sup>

of an operation which must necessarily terminate with as high or higher a moisture percentage in the discharged tailing as in the original pulp. At the Homestake, where this type of press is operated at a high efficiency for the treatment of low-grade slime, after amalgamation has recovered the bulk of the gold the presses are filled by gravity head pressure.

The **Sweetland Filter Press**, of intermittent operation, consists of a cylindrical filter body, divided on the horizontal center line into two halves which are hinged together (see Fig. 163).



A header is cast along the top half, through which holes are bored to receive the filter-leaf nipple outlets. The filter is locked by means of a series of swing bolts, which are tightened or loosened by means of an eccentric shaft. The filter leaf is a circular bag supported upon a wire-screen structure which prevents collapse of the bag and permits drainage of the clear liquor. In operation and after the displacement of the air the filter body is kept at a pulp pressure of about 40 lb. per sq. in. by means of gravity

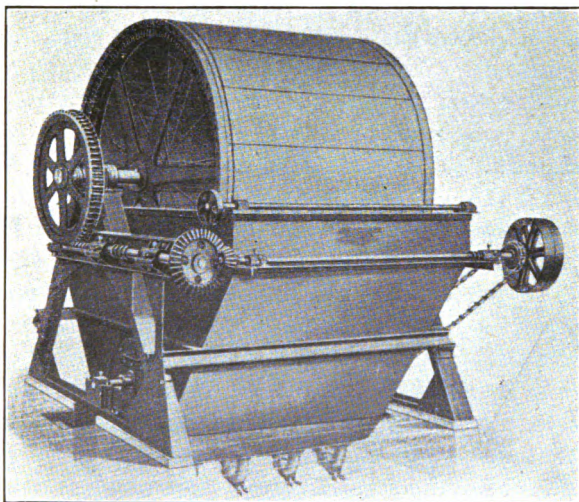


FIG. 164.—Revolving-drum type dewatering filter.<sup>31</sup>

pressure, pump, or montejus. The liquor passes out through the leaf and a cake is formed. The excess pulp in the shell may then be removed and the moisture percentage reduced by means of compressed air. Discharging is effected by opening the press, and by using a back current of air or steam to dislodge the cakes and free the pores of the filter medium.

**Metallic Filter Cloth** is an alloy in which nickel generally predominates, but may be made of copper, bronze, and other metals. This is drawn into fine wires, which are stranded and twisted.

The cloth is woven to give the desired texture and finally passed between rolls to flatten it and to produce the requisite degree of fineness.

**Dewatering by Vacuum** may be effected by means of a type of **Rotary Vacuum Filter** such as the **Oliver** or **Portland**. The principal requirements of such a machine when used for this purpose are: (a) automaticity and continuous action; (b) ample exposure to vacuum for drying without vibration or danger of cracking the cake; (c) provision for automatic discharge without necessity for air blast (which inevitably causes an increase in moisture percentage in discharged material by blowing back moisture already removed). With the rotary vacuum filter an air blow may be used to clear the pores of the canvas after the cake has been removed by scraper.

**Fine Material** to be dewatered in a **Rotary-Type Vacuum Filter** (see Fig. 164) is first thickened in a continuous machine, usually of the **Dorr** type. Details of the operation of **Portland** filters at the **Butte & Superior** mill on a flotation concentrate carrying 68.2 per cent. -200 mesh are given in Table XCI and show an average of under 8 per cent. moisture in the discharged product without steam-coil heating. With ordinary slimed ore it is practicable to reduce the moisture to from 10 to 20 per cent. with a machine of this type, according to the class of material being handled. In the case of a gold ore this permits efficient amalgamation and alkaline treatment, previous to cyanidation, without any subsequent accumulation of cyanide solution.

A combination **Dewatering Plant** for separate handling of coarse and fine material is shown in Fig. 165.

The **Shovel Wheel** for dewatering sand consists of a number of shovels attached to a wheel and which remove the sand from a trough. The shovels are usually perforated to facilitate drainage of the excess water and discharge of the sand. The **Cole Shovel Wheel** is shown in Fig. 166. This wheel is 24 in. in diameter and is fitted with 12 shovels of 1¼-in. scrap steel.



TABLE XCI.—PORTLAND FILTER DEWATERING TESTS AT THE BUTTE &amp; SUPERIOR MILL

| Test No. | Time             |                 | Vac., in. | Per cent.,<br>solid in<br>feed | Thickness,<br>cake, in. | Moisture,<br>per cent. | Capacity<br>per sq. ft.<br>filter area<br>per 24 hr.,<br>lb. |
|----------|------------------|-----------------|-----------|--------------------------------|-------------------------|------------------------|--------------------------------------------------------------|
|          | Loading,<br>min. | Drying,<br>min. |           |                                |                         |                        |                                                              |
| x2       | ½                | 5               | 22        | 61.91                          | ½                       | 9.72                   | 972                                                          |
| 3        | ½                | 6               | 22        | 61.91                          | ¾                       | 8.41                   | 672                                                          |
| x6       | ½                | 5               | 22        | 68.18                          | ¾                       | 6.89                   | 1608                                                         |
| 7        | ½                | 6               | 22        | 68.18                          | ¾                       | 5.93                   | 1704                                                         |
| x8       | ½                | 6               | 22        | 68.18                          | ¾                       | 6.36                   | 1392                                                         |
| 9        | ½                | 5               | 22        | 67.18                          | ½                       | 6.17                   | 1128                                                         |

NOTE.—Tests marked 'x' heated over steam coil while drying. Average capacity 14 ft. × 14 ft. Portland Filter with feed containing 44.6 per cent. solids, 194 tons per day; with feed containing 61.91 per cent. solids, 265 tons per day; with feed containing 67 to 68 per cent. solids, 403 tons per day. Average moisture in cake, without steam-coil heating, 7.87 to 7.28 per cent.

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